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ABSTRACT

This document contains an outline for a curriculum to train solar energy technicians in community colleges. The guide contains eight courses, each of which is divided into one to five modules. Modules, in turn, are divided into units, and units contain student handouts appropriate to the material. The following eight courses are included in this curriculum guide: (1) solar applications and future technology; (courses 2 and 3 missing); (4) introduction to solar energy, with modules on the sun and radiation, solar energy collection, solar energy storage, solar systems, and future outlook for solar; (5) control theory and application, with a module on general control; (6) materials and fabrication, with modules on basic materials, fabrication, and air distribution; (7) collectors and energy storage, with modules on collectors, solar storage, and installation; and (8) solar heating and cooling systems, with modules on system designs, retrofitting, and servicing. Prerequisites for persons entering the solar energy technician curriculum and a list of resources are included. (KC)

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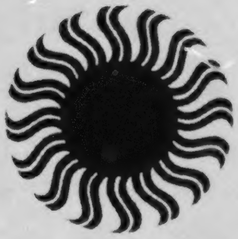

Solar Curriculum Guides
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Seward County Community College is indebted to several individuals and organizations for their contributions to this project. Their cooperation, service and guidance provided the assistance that made the project possible.

Nelson W. Dutton
Alternate Energy Instructor

Dr. James E. Hooper
President

PREREQUISITES: SOLAR ENERGY TECHNICIAN

1. The student must have the ability to use small machine and hand tools (electric drill, saw, pliers, hammers, and chisels).
2. The student must be able to weld, or learn how to weld.
3. The student must be able to lift 100 lbs over his/her head.
4. The student must be able to read at the fifth-grade level.
5. The student must be able to work in environments of extreme cold and hot climates, from -20° to +98°F.
6. The student must be able to work in close confines.
7. The student must be physically fit and cannot have physical handicaps of the type that would restrict the student from job duties. A student must be able to work on the roof of a house or apartment without getting dizzy.
8. The student must be able to be bonded.
9. The student should have an interest in air conditioning (HVAC) and/or plumbing.
10. Student should be interested in solar as an alternate source of energy.
11. A high school diploma or GED equivalency is desired but not required.
12. Assume knowledge of basic arithmetic operations, including addition, subtraction, multiplication, and division. Must be able to read charts.
13. Normal color vision is desired, but not essential.

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COURSE I: SOLAR APPLICATIONS AND FUTURE TECHNOLOGY

MODULE A: SOLAR APPLICATIONS

UNIT I: DOMESTIC HOT WATER

HANDOUT 1: INTRODUCTION

The earliest solar domestic hot water heating was introduced in the United States in Florida, 1936 to 1941. Natural gas was not available and electricity was 4¢ to 5¢ per KWH. In 1959 natural gas and electricity rate dropped to 3¢ per KWH, manufacturing and installing costs doubled, solar business was confined to small shops, the payback period was extended too long, little thought was given to engineering, credibility was questioned as leaks and replacements occurred, and the fast-buck salesmen overrated the systems--all of these created major problems.

Since then we have established a national development program, have acquired many solid solar system designs, have furnished education of the people and have had to face the rising cost of utility bills--thus solar energy is being revived.

Solar hot water systems may operate alone or they may be incorporated into solar heating or heating and cooling systems. Specific configurations for solar hot water systems vary widely, but they usually include the collector, storage, and auxiliary subsystems mentioned in conjunction with a baseline solar space heating system.

In active solar systems, hot water heating can be affected in a number of ways. The simplest is to route potable water directly through the collectors where it becomes heated and then is held in an insulated storage tank until a demand is initiated. As the tank is emptied, cool tap water is fed into the system. An electric heating element can be inserted in the water storage tank for auxiliary purposes. This system is usually only possible in warmer sunny climates where there is little possibility of the water freezing. In cooler climates, the collector fluid must usually contain an anti-freeze additive such as ethylene glycol, as well as corrosion inhibitors and in many cases biocides, anti-scalants, and pH controllers. Thus potable water is typically preheated indirectly from the storage subsystem via the use of heat exchangers.

In nontoxic water storage systems, the potable water may be routed through a heat exchange coil in the storage tank. The potable water is thus effectively preheated and is then pumped through a conventional water heater for further heating. The conventional water heating load is thus effectively reduced by the amount of preheating which can be supplied by the storage system. In the event that no preheat is available from storage, the conventional water heater provides the full heating requirement, thus functioning as an auxiliary unit. Toxic substances present in the storage media could create possible contamination dangers.

An alternative approach with a liquid storage system is to pump heated fluid from storage through a heat exchange coil located within a separate preheat tank filled with a nontoxic liquid heat transfer medium (typically water). Potable water is pumped through a separate heat exchange coil within the preheat tank. The transfer medium transfers heat from the storage fluid to the potable water, which is thereby preheated and subsequently pumped through a conventional auxiliary heater.

A third method is to locate the preheat tank directly within the storage tank (or within the rock bin when rocks are used as the storage media). The preheat tank is thus surrounded by the storage media which transfer heat directly through the tank walls, thus preheating the potable water which has been pumped in. The danger of contamination by toxic substances in the storage media is also apparent with this system.

Potable water can also be heated using a passive solar system. Movement of water in and out of the collector can be carried out through the use of thermosyphoning where transport is effected using the density differential between different temperature masses of water. Cool domestic water is fed to the bottom of a storage tank which is placed above the solar collector. From there it is allowed to enter the collector at the bottom. As the collector becomes heated by solar radiation, the water is heated and is naturally circulated upward through the collector by convection, after which it flows back to the top of the storage tank. As demand is initiated, the heated water is drawn from the top of the tank and is fed by gravity either directly to the dwelling or through a conventional water heater.

COURSE I: SOLAR APPLICATIONS AND FUTURE TECHNOLOGY

MODULE A: SOLAR APPLICATIONS

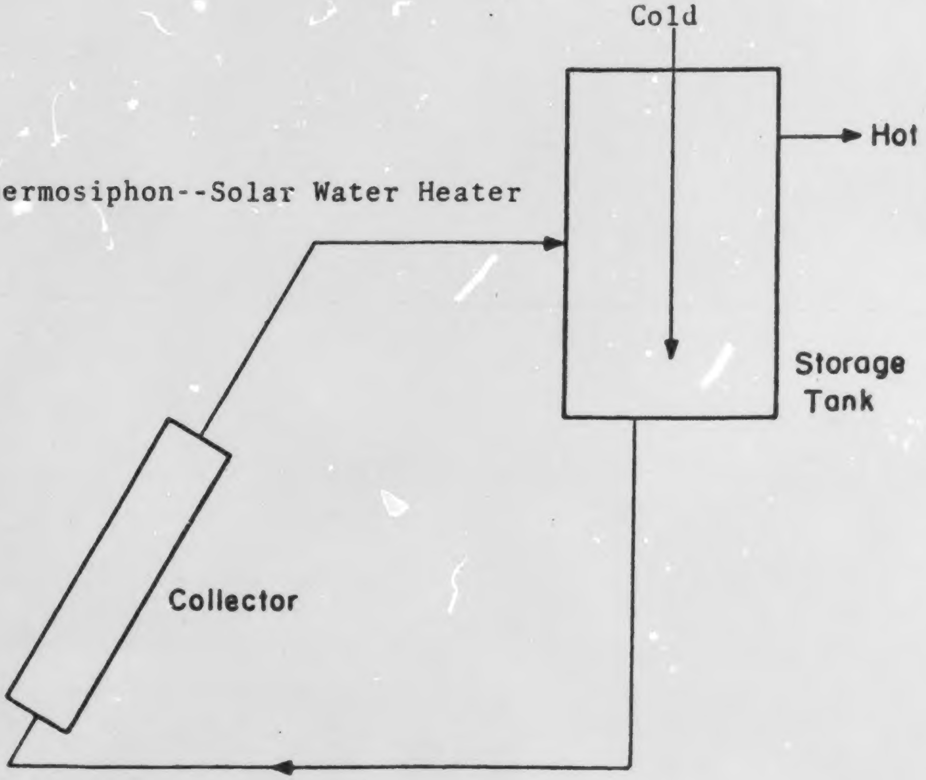
UNIT I: DOMESTIC HOT WATER

HANDOUT 2: TYPES OF HOT WATER SYSTEMS

Using the sun to heat our hot water the year around is and has been the most practical use of solar energy.

PASSIVE SYSTEM--DIRECT HEATING
(Warm Climate)

In non-freezing climates a thermosiphon solar water heater is used. A diagram is shown below.


Thermosiphon--Solar Water Heater

The collector, usually single glazed, may vary in size from about 20 square feet to 100 square feet and the insulated storage tank may range from 30 to 120 gallon.

Operation at supply pressure can be provided if the system is so designed. With a float valve in the storage tank or in an elevated head tank, unpressurized operation can be obtained if the system is not designed for pressure. Gravity flow from the hot water tank to hot water faucets would have to be accepted, or an automatic pump would have to be provided in the hot water line to supply pressure service. Plumbing systems and fixtures in the United States usually require the pressurized system.

Location of the tank higher than the top of the collector permits circulation of water from the bottom of the tank through the collector and back to the top of the tank. The density difference between cold and hot water produces the circulating flow. Temperature stratification in the storage tank allows for operation of the collector under most favorable conditions, water at the lowest available temperature being supplied to the collector and the highest available temperature being provided to service. Circulation occurs only when solar energy is being received, so the system is self-controlling. The higher the radiation level, the greater the heating and the more rapid the circulating rate will be.

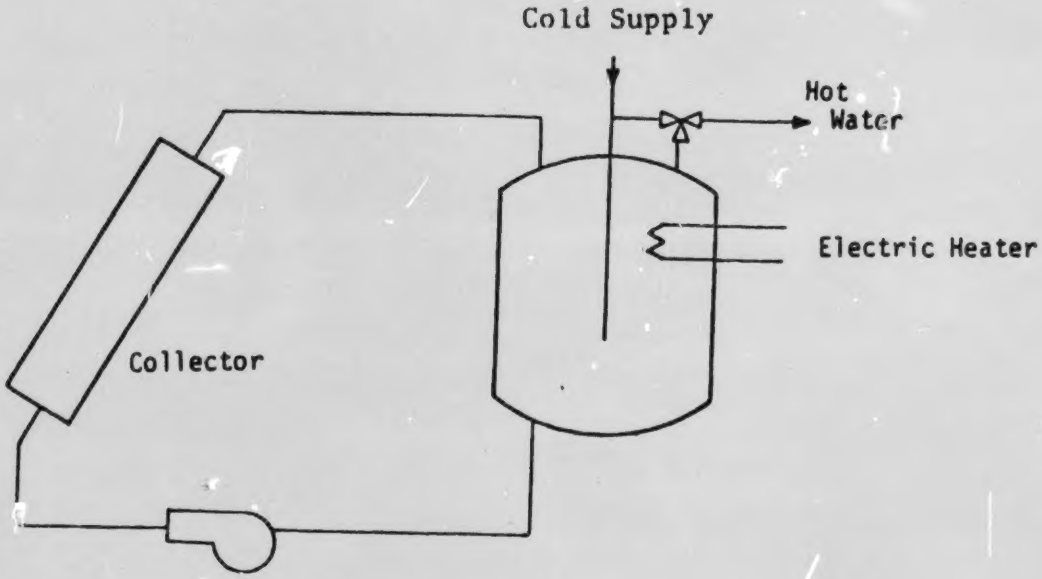
In a typical collector under a full sun, a temperature rise of 15°F to 20°F is commonly realized in a single pass through the collector.

To prevent reserve circulation and cooling of stored water when no solar energy is being received, the bottom of the tank should be located above the top header of the collector. If the collector is on a house roof, the tank may also be on the roof above the collector or in the attic space at a height that exceeds the top header of the collector.

Do not use the thermosiphon system in cold climates without researching a collector draining technique.

ACTIVE SYSTEM--DIRECT HEATING
(Warm Climate)

If placement of the storage tank above the collector is not convenient or not possible, the tank may be located below the collector and a small pump used for circulating water between collector and storage tank. This arrangement is usually more practical than the thermosiphon type in the United States, because the collector would often be located on the roof with a storage tank in the basement. Instead of thermosiphon circulation when the sun shines, a temperature sensor actuates a small pump which circulates water through the collector-storage loop. A schematic arrangement is shown on the following page. To obtain maximum utilization of solar energy, control is based on the difference in water temperature at collector outlet and bottom of storage tank.



Direct Heating--Pump Circulating

Whenever this difference exceeds a preset number of degrees the pump motor is started. The sensor at the collector outlet must be located close enough to the collector so that it is affected by collector temperature even when the pump is not operating. Similarly, the sensor in the storage tank should be located in or near the bottom outlet from which the collector is supplied. When the temperature difference falls below the preset value, the pump is shut off and circulation stops. To prevent reverse thermosiphon circulation and consequent water cooling when no solar energy is being received, a check valve should be located in the collector feed-side of the circulation line.

If hot water consumption is not sufficient to maintain storage tank temperature at normal levels, boiling may occur in the collector. If a check valve or pressure-reducing valve prohibits back flow from the storage tank into the main, a relief valve must be provided in the collector-storage loop. The relief valve will permit the escape of steam and prevent damage to the system.

ACTIVE SYSTEM--DIRECT HEATING
(Cold Climate)

If the solar water heater described above is used in a cold climate, it may be protected from freeze damage by draining the collector when sub-freezing temperatures are encountered. Several methods can be used. Their common requirement, however, is reliability, even when electric power may not be available.

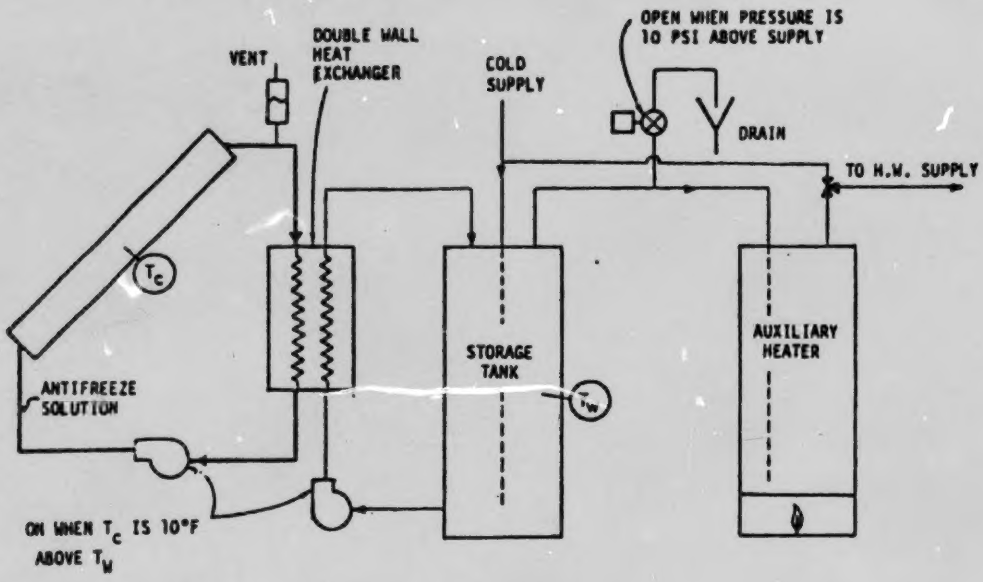
Drainage of the collector in freezing weather can be accomplished by automatic valves which provide water outflow to a drain and the inflow of air to the collector. The control system can be arranged so that whenever the circulating pump is not in operation, these valves are open. To assure maximum reliability, the valves should be mechanically driven to the drain position (by springs), rather than electrically, so that in the event of a power failure, the collector can automatically drain.

The drainage system is actuated by a temperature sensor in the collector. When the sensor indicates a possibility of freezing, it can open drainage and vent valves, thus providing protection. The temperature sensor can be of the vapor pressure type, with capillary tube connections to mechanical valve actuators, or of the electrical type where the valves are held open by electrical means, automatically closing either when electrical failure occurs, or at low temperatures.

ACTIVE LIQUID SYSTEM--INDIRECT HEATING
(Cold Climate)

As can be inferred from the above discussions of needs and means for collector drainage in freezing climates, costs and hazards are involved with those systems. The drainage requirement can be eliminated by the use of a non-freezing heat transfer medium in the solar collector, and a heat exchanger for transfer of heat from the solar heat collecting medium to the service water. The collector need never be drained, and there is no risk of freezing and damage. Corrosion rate in the wet collector tubes is also decreased when intermittent admission of oxygen is not permitted.

The following page illustrates a method for solar water heating with a liquid heat transfer medium in the solar collector. The most commonly used liquid is a solution of propylene glycol in water. A pump circulates this unpressurized solution, as in the direct water heating system, and


VENT
DOUBLE WALL HEAT EXCHANGER
COLD SUPPLY
OPEN WHEN PRESSURE IS 10 PSI ABOVE SUPPLY
DRAIN
TO H.W. SUPPLY
T_c
STORAGE TANK
AUXILIARY HEATER
T_w
ANTIFREEZE SOLUTION
ON WHEN T_c IS 10°F ABOVE T_w

Dual Liquid Solar Hot Water Heater

delivers the liquid to and through a liquid-to-liquid heat exchanger. Simultaneously, another pump circulates domestic water from the storage tank through the exchanger, back to storage. The control system is essentially the same as that in the design employing water in the collector directly. If the heat exchanger is located below the bottom of the storage tank, and if the pipe sizes and heat exchanger design are adequate, thermosiphon circulation of water through the heat exchanger can be used. A small expansion tank needs to be provided in the collector loop, preferably near the high point of the system, with a vent to the atmosphere.

To meet most code requirements, the heat exchanger must be of a design such that rupture or corrosion failure will not permit flow from the collector loop into the domestic water, even if pressure on the water side of the exchanger drops below that on the antifreeze side. A conventional tube-and-shell exchanger would therefore not usually be acceptable. Similarly, a coil inside the storage tank, through which the collector fluid is circulated, would not be satisfactory. Parallel tubes with metal bonds between them, so that perforation of one tube could not result in liquid entry into the other tube, would be a suitable design. A finned tube air-to-liquid heat exchanger could also be used by circulating the two liquids through alternate rows of tubes, heat transfer being by conduction through the fins.

Although an aqueous solution of propylene glycol appears to be the most practical for solar energy collection, organic liquids such as Dowtherm J and Therminol 55 may be employed. Price and viscosity are drawbacks, but chemical stability and assurance against boiling are advantages over the antifreeze mixture.

ACTIVE AIR SYSTEM--INDIRECT HEATING

In a manner similar to that described immediately above, solar energy can be employed in an air heating collector with subsequent transfer to domestic water in an air-to-water heat exchanger. A solar air heater is supplied with air from a blower, the air is heated by passage through the collector, and the hot air is then cooled in the heat exchanger through which domestic water from a storage tank is either being pumped or is circulating by thermosiphon action. Air from the heat exchanger is recirculated to the collector. Differential temperature control (between collector and storage) is employed as in the other systems described. Advantages of the air heat transfer medium are the absence of corrosion in the collector loop, freedom from liquid leakage, and freedom from boiling and loss of collector fluid. Disadvantages are the larger conduit between collector and heat exchanger, higher power consumption for circulation, and slightly larger collector surface requirements.

AUXILIARY HEAT

A dependable supply of hot water requires the availability of auxiliary heat for supplementing the solar source. The numerous methods of providing auxiliary heat vary in cost and effectiveness. A general principle for maximizing solar supply and minimizing auxiliary use is the avoidance of direct or indirect auxiliary heat input to the fluid entering the solar collector. If auxiliary heat is added to the solar hot water storage tank, so that the temperature of the liquid supplied to the collector is increased above that which only the solar system would provide, efficiency is reduced because of higher heat losses from the collector. Thus, auxiliary heat should be added at a point beyond (downstream from) the solar collector-storage system. Any deficiency in temperature is made up by fuel in the conventional heater with a thermostat. Alternatively, a "fast response", in-line heater can be employed. It is evident that auxiliary heat supply in these designs cannot adversely affect the operation of the solar system.

Another way in which auxiliary heat can be used without reducing solar collection efficiency is by electric resistance heaters in the upper portion of the solar storage tank. Temperature stratification in the tank, accomplished by bringing cold water from the main into the bottom and by circulating through the collector from the bottom of the tank to the upper portion of the tank, thereby prevents auxiliary heat from increasing the temperature of the water supplied to the collector. Water returning from the collector may be brought into the tank well below the level of the resistance heater so that the hot supply is always available at the thermostatted temperature. If relatively high temperature water is desired, there may be an undesirable influence of auxiliary supply on collector efficiency because of some mixing in the tank.

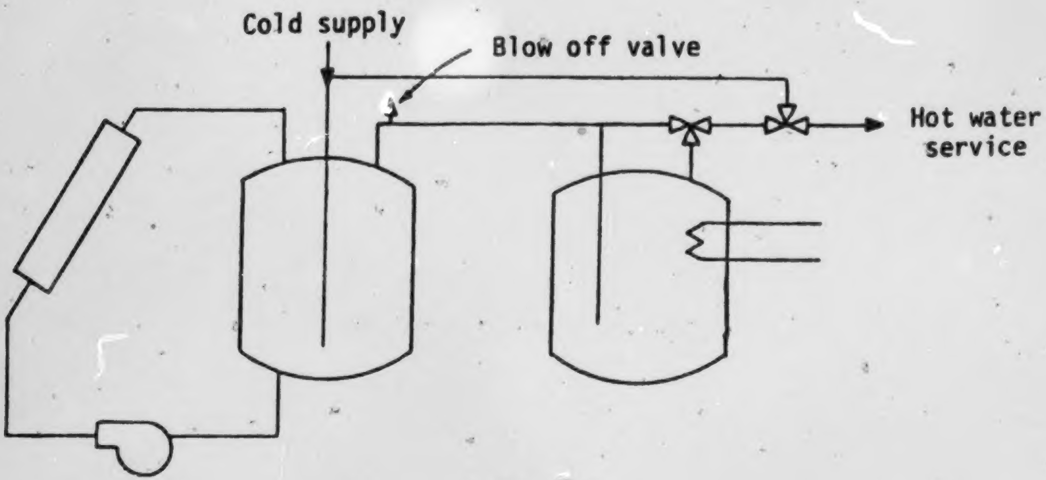
Although the description of the above systems refers to direct circulation of water through the collector, the same factors apply to the systems involving heat exchange with antifreeze solutions or air circulating through the collector. In all cases, auxiliary heat should be supplied downstream from the solar storage tank, regardless of whether the water itself is circulated through the collector or whether heat is exchanged between the domestic water and a solar heat transfer fluid.

TEMPERATURE STRATIFICATION IN SOLAR HOT WATER STORAGE TANK

As in a conventional hot water heater, the temperature in the upper part of a solar hot water tank will normally be considerably higher than at the bottom. The lower density of hot water allows this stratification, provided that turbulence at inlet and outlet connections is not excessive. The supply of relatively cold water from the bottom of the tank to the collector allows the collector to function at its highest possible efficiency under the prevailing ambient conditions. With a circulation rate such that a temperature rise through the collector of 15°F to 20°F occurs, the lower part of the storage tank is furnished to the collector for maximum effectiveness. If very little hot water is withdrawn from the tank during a sunny day, the late afternoon temperature at the bottom of an 80 gallon tank connected to a 40-to-50 square foot collector may be well above 140°F--even nearing the temperature in the top of the tank. Collection efficiency thus varies throughout the day, depending on solar availability and on the temperature of water supplied to the collector from the tank bottom.

TEMPERATURE CONTROL LIMIT

In addition to the differential temperature control desirable in most solar water heating systems (which sense temperature difference between collector and storage), protection against excessive water temperature may be necessary. A number of possible methods can be used. In practically all types of systems, whether direct heating of the potable water or indirect heating through a heat exchanger, a thermostatically controlled mixing valve can be used to provide constant temperature water for household use. The following diagram illustrates one method by which this type of temperature control can be accomplished.



Cold water is entered into the hot water line immediately downstream from the auxiliary heater in sufficient proportion to secure the desired preset temperature. The solar hot water tank is permitted to reach any temperature attainable, and the auxiliary heater provides additional energy only when the auxiliary tank temperature falls below the thermostat set point. Maximum solar heat delivery is thus achieved, and no solar heat needs to be discarded except that which might sometimes be delivered when the main storage (preheat) tank is at the boiling point. Any additional solar heat collected under that condition will be dumped through a pressure relief valve, letting steam escape to the surroundings.

An option, that appears considerably more practical than the pressurized collector required with aqueous systems if the dual-liquid design is utilized, is to use heat transfer fluids having high boiling points. Downtherm J or Therminol 55 have boiling points above 300°F, so if one of these fluids is used, the development of pressure in the collector loop would not occur, even when the storage system is venting steam at 50 psi.

Another option for high-temperature protection is available if the collector is used as a heater for a high-boiling organic liquid or for air. To prevent the storage tank from reaching a temperature higher than desired, a limiting thermostat in that tank can be used simply to discontinue circulation of the heat transfer fluid (organic liquid or air) through the collector and heat exchanger. No additional heat is therefore dissipated in the form of collector heat loss. The collector temperature rises substantially, frequently above 300°F, but if properly designed, the collector suffers no damage. This system is probably the safest and most dependable of those herein described. With a reliable limit switch in the storage tank, there can be no dangerous pressure developments anywhere in the system. In addition, there is no loss of water (in the form of steam) even when there is no use of hot water for long periods.

Most single-glazed collectors will reach a maximum temperature--heat lost from collector is equal to heat gained by the collector--somewhat below the temperature of boiling water. A single-glazed collector is less expensive, safe, and usable especially in warm and temperate climates. A single-glazed collector should be given consideration for hot water heating in locations where build-up pressures and excess temperatures are a concern.

HOT WATER NEEDS

An average family of four persons uses, in the United States, about 80 gallons of hot water each day. At a customary supply temperature of about 140°F, the amount of heat required if the cold inlet is at 60°F is about 50,000 BTU per day.

There is a wide variation in the solar availability from region to region and from season to season in a particular location. There are also the short-term radiation fluctuations due to cloudiness and the day-night cycle.

Seasonal variations in solar availability result in a 200 to 400 percent difference in the solar heat supply to a hot water system. For example, in the winter an average recovery of 40 percent of 1200 BTU of solar energy per square foot of sloping surface would require approximately 100 square feet of collector for the 50,000 BTU average daily requirement. Such a design would provide essentially all of the hot water needs on an average winter day, but would fall short on days of less than average sunshine. By contrast, a 50-percent recovery of an average summer radiant supply of 2000 BTU per square foot would involve the need for only 50 square feet of collector for satisfying the average hot water needs.

It is evident that if a 50-square-foot collector were installed, it could supply the major part, perhaps nearly all, of the summer hot water needs, but it could supply less than half the winter requirements. If, on the other hand, a 100-square-foot collector were used in order that winter requirements could be more nearly met, the system would be oversized for summer operation and excess solar heat would have to be wasted. In such circumstances, if an aqueous collection medium were used, boiling of the system would occur and collector or storage venting of steam would have to be provided.

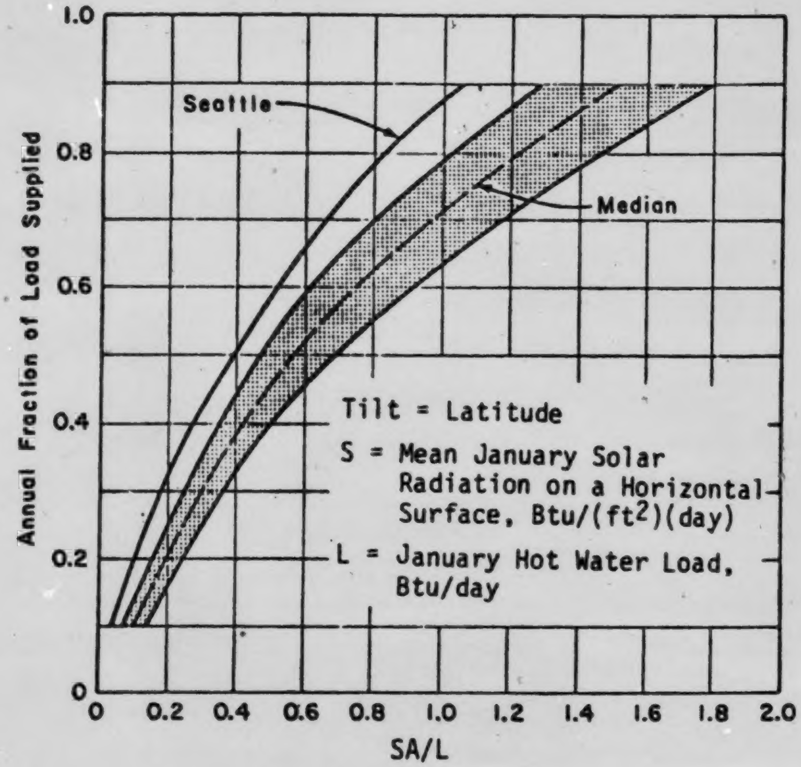
A more important disadvantage of the oversized collector (for summer operation) is the economic penalty associated with investment in a collector which is not fully utilized. Although the cost of the 100-square-foot collector would be approximately double that of the 50-square-foot unit, its annual useful heat delivery would be considerably less than double. It would, naturally, deliver about twice as much heat in the winter season, when nearly all of it could be used, but in the other seasons, particularly in summer, heat overflow would occur. The net effect of these factors is a lower economic return, per unit of investment, by the larger system. Stated another way, more BTU per dollar of investment (hence cheaper solar heat) can be delivered by the smaller system.

Overall, practical design of solar water heaters should be based on desired hot water output in the sunniest months rather than at some other time of year. If based on average daily radiation in the sunniest months, the unit will be slightly oversized and a small amount of heat will be wasted on days of maximum solar input. Then, quite evidently, on cloudy days during the season, some auxiliary heat must be provided. In the month of lowest average solar energy delivery, typically one-half to one-third as much solar heated water can be supplied, or actually the same quantity of water but with a temperature increase above inlet only one-half to one-third as high. Thus, fuel requirements for increasing the temperature of solar heated water to the desired (thermostatted) level could involve one-half to two-thirds of the total energy required for hot water heating in a mid-winter month.

SIZING

It should be remembered that the service hot water load will be nearly constant throughout the year while the solar energy collected will vary from season to season. A system sized for January, with collectors tilted at the latitude angle, will deliver high temperature water and may even cause boiling in the summer. On the other hand, a system sized to meet the load in July will not provide all of the load in the winter months. Orientation of the collector can partially overcome month-to-month fluctuations in radiation and temperature.

The following sizing curves are approximate and should not be expected to yield results closer than 10 percent of actual value.



Fraction of Annual Load Supplied by Solar as a Function of January Conditions for Hot Water Heaters

Sizing Examples:

A-1. Determine the approximate size of collector needed to provide hot water for a family of four in a residential building in Liberal, Kansas.

Solution: The average daily service hot water load in January is:

$$L = 80 \text{ gallons/day} \times 8.34 \text{ pounds/gallon} \times 1 \text{ BTU/(lb)}(^{\circ}\text{F})$$
$$\times (140^{\circ}\text{F} - 55^{\circ}\text{F}) = 56{,}712 \text{ BTU/day}$$

The desired service water temperature is 140°F and the temperature of the cold water from the main is 55°F. The total average solar radiation, S, available in January, taken from page A-36, is 940 BTU per square foot per day. For a water system to provide 60 percent of the annual load, from page A-34, SA/L is about 0.8. Therefore:

$$A = 0.8 \times L/S = (0.8 \times 60048)/680 = 48.3 \text{ square feet}$$

If 3-by-8-foot collector modules are available, 2.0 units would be required.

Example:

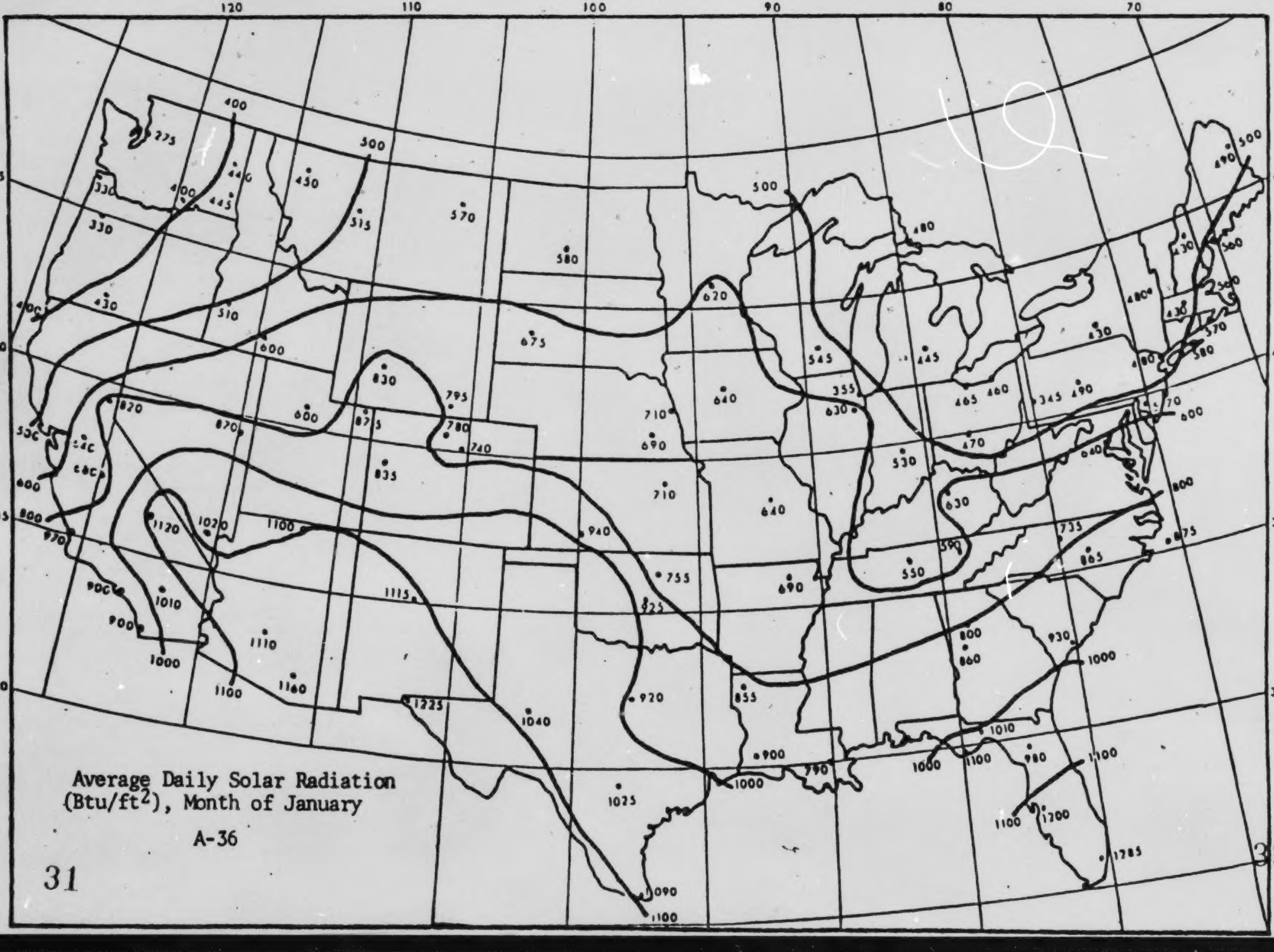
A-2. Determine the size of collector needed to provide hot water for a family of four in Albuquerque, New Mexico.

Solution: The monthly load will be approximately the same as in Example A-1:

$$L = 56{,}712 \text{ BTU/day}$$

From page A-36, $S = 1115 \text{ BTU/(ft}^2\text{)(day)}$. For a system to provide 60 percent of the annual load, page A-34 shows that SA/L is approximately 0.8.

A-24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460
345
490
470
600
355
630
640
710
690
600
830
795
780
740
870
820
875
835
530
640
630
710
590
550
640
735
865
875
940
755
690
925
920
855
900
790
1000
1010
1000
1100
980
1100
1100
1700
1785
930
1000
800
860
1040
1025
1090
1100
1225
1115
1110
1160
1100
1000
1010
900
900
970
1120
1020
1100
1000

Average Daily Solar Radiation (Btu/ft^2), Month of January

A-36

The collector area required is:

$$A = (0.8 \times 60048)/1115 = 40.7$$

Using 3 by 6 foot collector modules, 2.3 units would be required for this system--either two or three modules should be used. If two modules are used, the system would be expected to provide less than 60 percent of the annual load.

COURSE I: SOLAR APPLICATIONS AND FUTURE TECHNOLOGY

MODULE A: SOLAR APPLICATIONS

UNIT II: SWIMMING POOL HEATING

HANDOUT 1: INTRODUCTION

Solar collectors can be used to heat swimming pools that are both indoors and out-of-doors. Collectors used to heat outdoor pools are usually less elaborate than space heating collectors simply because they are used in the spring and summer months. Thus, single glazed or even unglazed absorber panels can be used. Many unglazed panels are made of plastic or rubber as well as metal. However, in the case of metal, swimming pool water is never circulated through all-aluminum panels because of excessive corrosion.

Under natural conditions, pool water will gain some heat during the day and then lose some heat at night. Typically, pool water may exceed the average ambient temperature by up to 10 degrees under these conditions.

Outdoor swimming pools lose heat in several ways, namely by:

1. conduction through the pool material to the ground.
2. convection at the pool surface.
3. evaporation at the pool surface.
4. radiation at the pool surface.

Conduction losses are usually small relative to the other modes of heat loss. Thus, to make full use of any solar assist (natural or with panels), outdoor pools should be provided with pool covers so that convective, evaporative, and radiation losses are minimized.

One type of pool cover of particular interest to the solar technician is the transparent cover. This product allows considerable solar energy to pass through during the day to help heat the pool water as well as minimize pool heat losses at night.

Considering typical pool heat losses, the usual rule-of-thumb sizing procedure suggests that, for adequate performance, the collector area should equal half the pool area for south facing collectors. For other directions, additional area is required.

Proper tilt depends on the season of the year for which pool heating is desired. In northern climates, pool heating is generally required in the summer, thus the preferred tilt is latitude minus 10 degrees. In southern areas, winter pool heating might be the objective. In this case, the preferred tilt is latitude plus 10 degrees.

Most manufacturers of collectors intended for pool applications offer design assistance and make recommendations on control of the system.

COURSE I: SOLAR APPLICATIONS AND FUTURE TECHNOLOGY

MODULE A: SOLAR APPLICATIONS

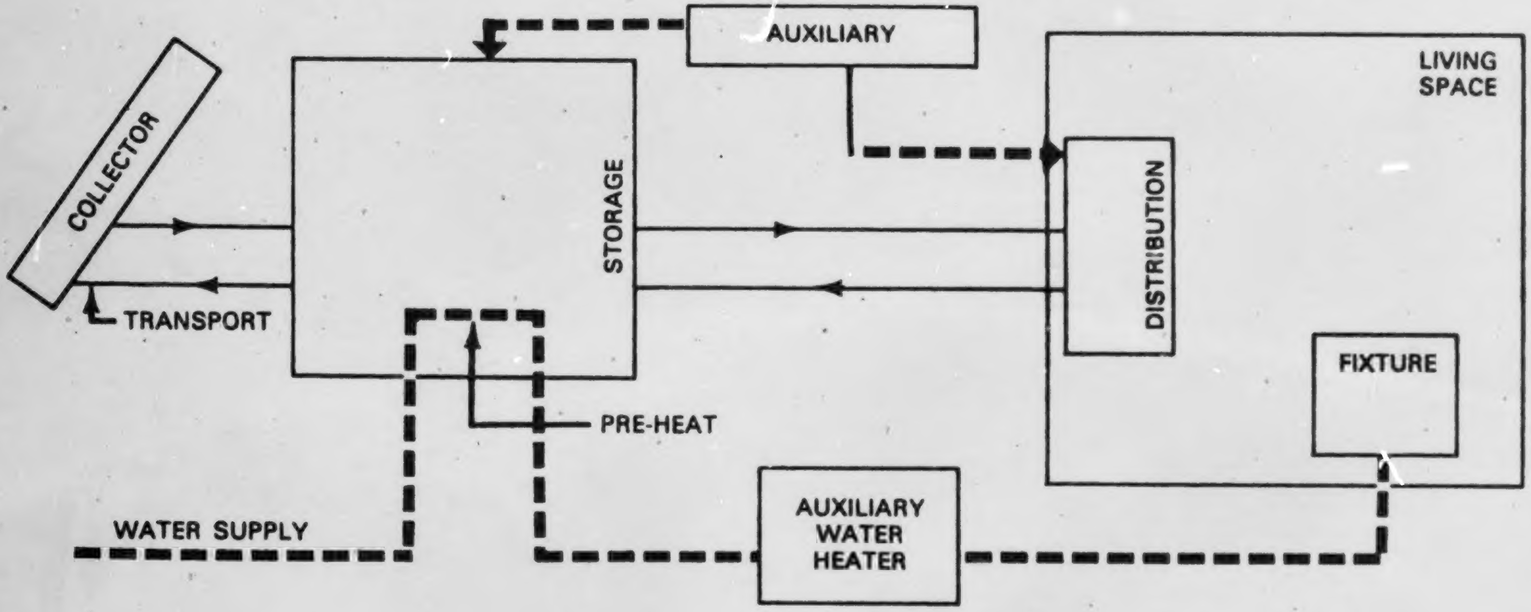
UNIT III: SPACE HEATING

HANDOUT 1: TYPES OF SYSTEMS

Solar heat from the collectors and the heating demand for a building are not normally in balance. Thus, mechanical equipment is required for proper comfort control. The central component of the solar system is the heat storage unit. The heat storage unit receives heat from the collectors when the solar heat exceeds the heating load and delivers heat to the rooms when the heating load exceeds the solar heat available from the collectors. When solar heat has been depleted from storage, the auxiliary boiler or furnace supplies the heat to meet the heating load. The system should be easy to operate, require little maintenance, and provide the comfort level demanded by the occupants in the building.

The most commonly used solar system today is a combined solar heating and domestic hot water system. Solar radiation is absorbed by a collector and removed by a heat transport medium to storage. Heat is removed from storage and distributed to the living spaces by a heat transfer medium (not necessarily the same medium flowing through the collector).

SOLAR HEATING AND DOMESTIC HOT WATER SYSTEMS: PROCESS DIAGRAM


AUXILIARY
LIVING SPACE
COLLECTOR
STORAGE
DISTRIBUTION
TRANSPORT
FIXTURE
PRE-HEAT
WATER SUPPLY
AUXILIARY WATER HEATER

Pumps, blowers, or other heat transfer medium-moving devices provide the circulation throughout the system. An auxiliary energy system is available both to supplement the output supplied by the solar system and to provide for the total energy demand should the solar system become inoperable. Manual or automatic controls maintain and monitor system operation. Domestic hot water is preheated by passing the water supply through a heat storage before its passage through a water heater.

By the positioning of three-way dampers (or valves) and the controlling of blowers (or pumps) on or off, three "modes" of operation are possible:

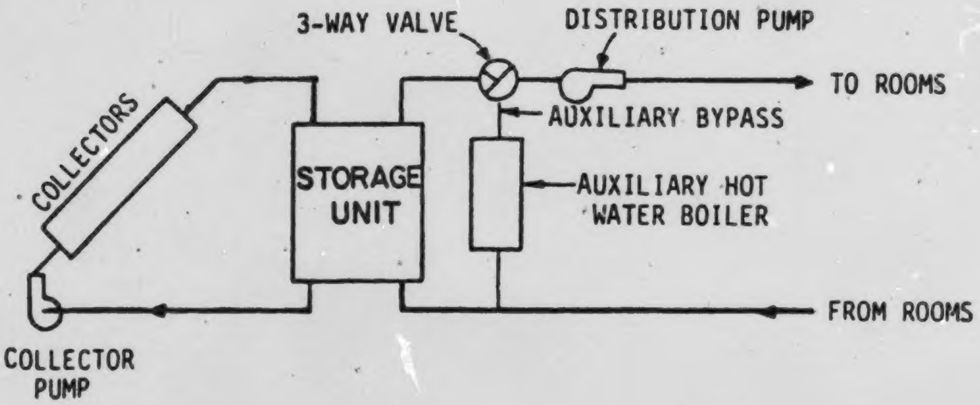
1. Heating the building directly from the collectors
2. Heating the storage unit from the collectors
3. Heating the building from the storage unit

In a water system the collection and distribution circuits may each be connected to the water storage tank and the three-way valves may be eliminated. The three modes are obtained by on and off control of the two pumps.

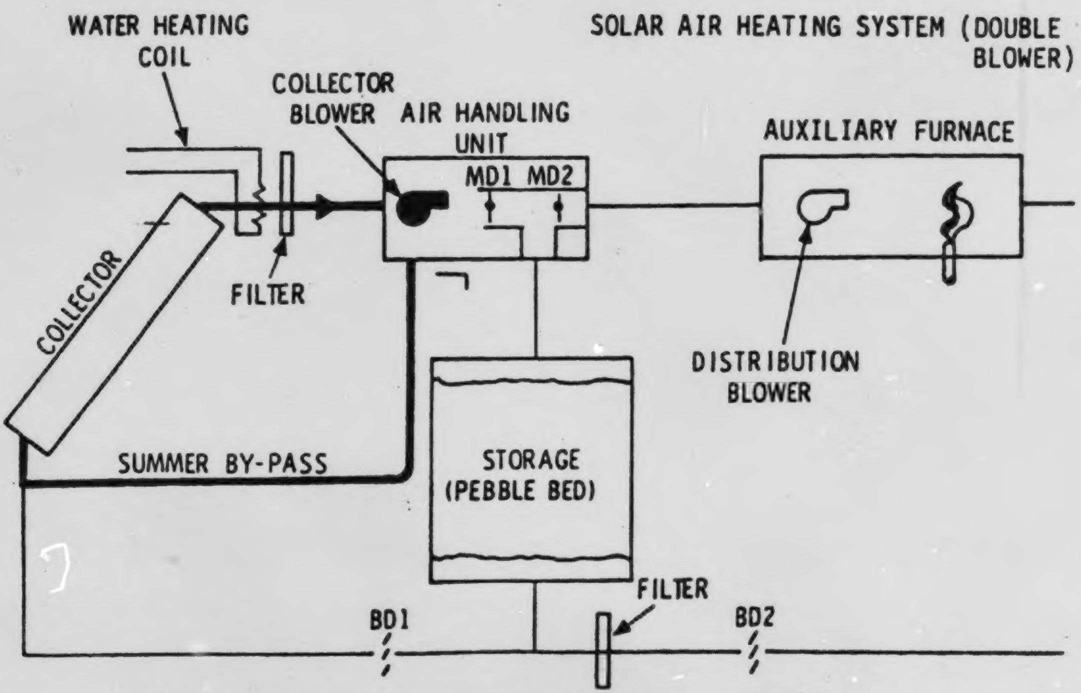
Since there are periods when neither the collectors nor the storage unit can meet the demand for heat, an auxiliary heater (fuel or electric) having the capacity to carry the maximum heating load is required. Solar and auxiliary heat may be supplied to the building by the same heat distribution system. The air heating solar system may use a conventional warm-air furnace directly in the hot air supply duct. Fuel is supplied to the auxiliary unit only when solar heat is insufficient to maintain the desired room temperature.

In the liquid system a hot water boiler (fuel or electric) is used, preferably locating the boiler in a by-pass circuit as shown on the following page. The boiler by-pass is used to prevent heating the storage with auxiliary energy. Heat from the auxiliary boiler should not be supplied to the storage tank because it is wasteful use of energy.

Liquid System for Solar Space Heating with Auxiliary Boiler


3-WAY VALVE
DISTRIBUTION PUMP
TO ROOMS
COLLECTORS
STORAGE UNIT
AUXILIARY BYPASS
AUXILIARY HOT WATER BOILER
FROM ROOMS
COLLECTOR PUMP

So that the domestic hot water supply can be solar heated in the summer when no space heating is needed, the heat storage unit and heated space can be by-passed as shown below.


WATER HEATING COIL
SOLAR AIR HEATING SYSTEM (DOUBLE BLOWER)
COLLECTOR BLOWER
AIR HANDLING UNIT
MD1 MD2
AUXILIARY FURNACE
COLLECTOR
FILTER
DISTRIBUTION BLOWER
SUMMER BY-PASS
STORAGE (PEBBLE BED)
FILTER
BD1
BD2

Service Hot Water Heating (Summer Operation)

A manual damper is opened in the by-pass duct so that air is circulated in a closed loop between collector, water heating coil, and the collector blower. Damper MD 1 in the closed position prevents flow of hot air to storage or the rooms.

Most commercially available warm-air furnaces for residential use contain a blower for circulation of warm air through the building via the distribution ducts. In a typical all-air solar installation, the furnace blower is used in the normal manner for distributing warm air--supplied either from the collectors or from storage. The solar system blower operates only when air is circulated through the collector.

SOLAR AIR SYSTEM, COMPONENTS, AND INSTALLATION

Important operating considerations in the air type system are blower power requirements and air leakage. A well-designed air system has approximately equal pressure loss through the collectors and pebble-bed, typically about 0.3 inch water guage in each unit. With ducting and filters, the total system pressure can near one inch of water. The total pressure in an air type solar system is about double that usually encountered in a conventional forced air distribution system, so additional blower power is needed. Typical requirement in a conventional system is one-half to three-fourths horsepower for a 1500 cfm system. The blowers also run for longer periods of time than in the conventional system because of their use both for solar heat collection and for heat distribution. A one-inch water guage pressure loss is about the maximum acceptable from the standpoint of blower power cost.

Leakage of air in ducts, collectors, and storage is of more concern in a solar heating system than in a conventional system because the pressure is higher, there is more ducting, the system operates for longer periods, and there may be more ducting through unheated space. The ducts should, therefore, be made with sealed joints and tightly fitted dampers. The ducts may be of fiberglass board or insulated sheet metal. Insulation is required to reduce heat loss through the duct walls, particularly in unheated spaces such as attics, At least one inch of fiberglass with a rating of R-4 is recommended for duct insulation.

It is especially important with a solar air system that a well scheduled installation be made. More space and access must be provided in the building for ducting than for pipes in a liquid system. Ductwork and component assembly can be accomplished at the same time that the distribution ducts and furnace are installed in a typical construction schedule. Provision for construction and installation space and for full access to the space for systems and components is required.

If fiberglass ductboard is used for the air duct, it should not be placed where it can be damaged by moving objects or occupants. Joints should be well sealed with tapes or mastics recommended by the industry. Duct bends should be provided with turning vanes to reduce losses. Ducts should be sized for air velocities between 700 and 1000 feet per minute.

Blowers, dampers, and auxiliary heaters may be provided by a single solar system supplier or they may be purchased separately. If separately purchased, blowers should be forward-curved squirrel cage type and belt-driven at 900 to 1700 rpm. Direct connected blowers with motors in the air stream may have briefer service life because of motor operation in high-temperature air. Flexible connections between blowers and ducts are recommended.

Louver-type dampers with live silicon rubber seals are recommended for positive shut off and smooth stroking. Damper drive motors should be located on the outside of ducts and direct connected to the damper shaft or through linkages. Damper pairs may be operated by the same drive motor such that one is closed when the other is open. Damper motors are available that operate on low voltage (24 volt) and have spring returns.

Back draft dampers, used in ducts to prevent reverse flow, may be of the flexible flat type or shutter type. They must be mounted to provide a positive seal against reverse air flow.

To prevent fouling and increased pressure loss in the pebble-bed, filters should be installed in the air streams entering both ends of the storage unit. The filters should be changed or cleaned every few weeks during the first several months of operation to remove the initial dust in the system and building.

Provision for supply of domestic hot water can be easily made in the air system by the use of an air-to-water heat exchanger in the hot air duct between the collector and blower. The heat exchanger coil is a finned type, with one or two rows of tubes. A small pump circulates water from the bottom of an insulated tank (usually about 80-gallon capacity), through the coil, and back to the top of the tank. The cold water enters the solar-heated tank and warm water flows to a conventional automatic water heater whenever a hot water faucet is opened in the building. A duct by-pass allows operation of the service hot water coil in the summer without heating the pebble-bed. A thermostatic mixing valve can be installed in the line connected to the service hot water tank from the cold water main to prevent delivery of scalding hot water.

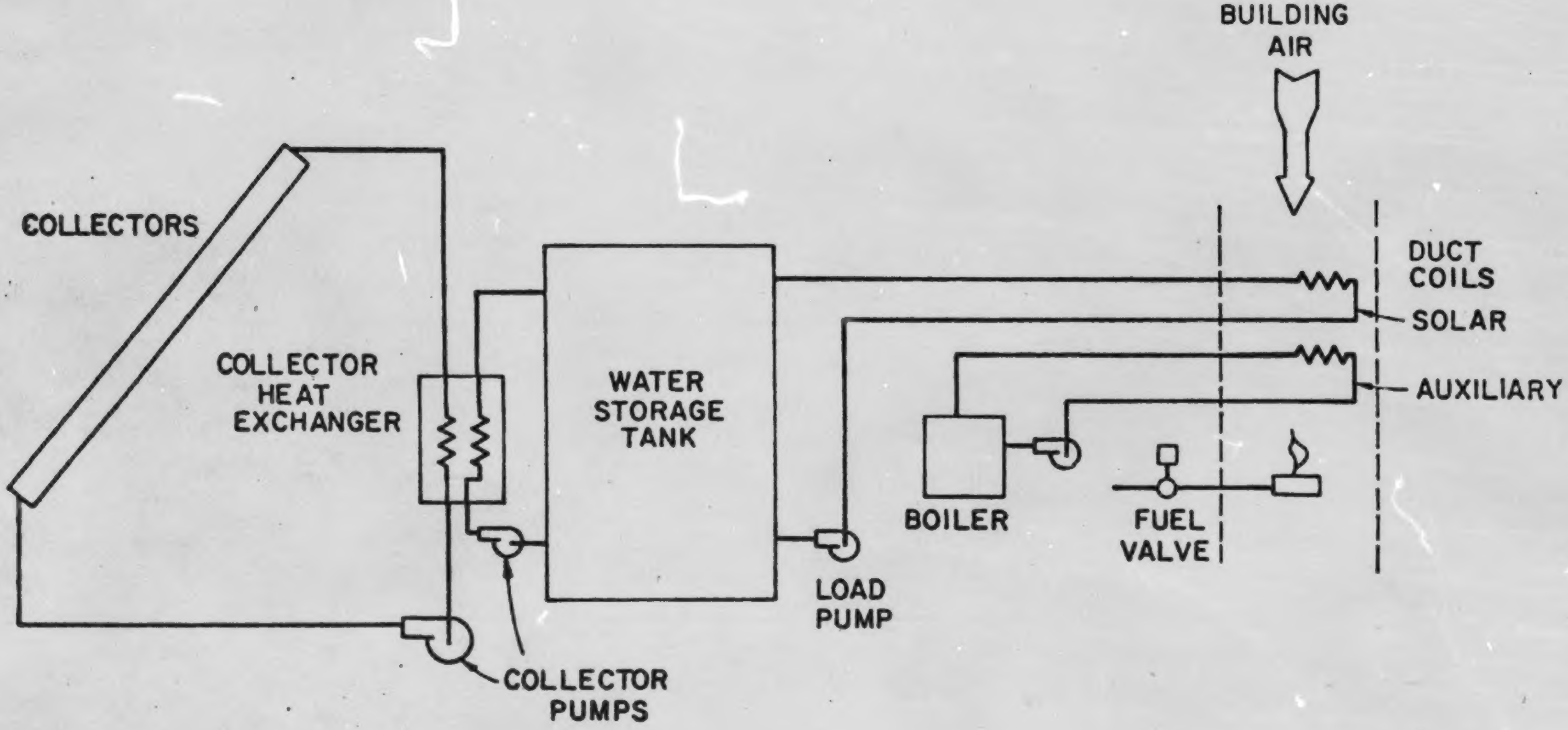
The complete solar heating installation will require heating and sheet metal workers to install collectors, ducts, dampers, plumbers to connect the domestic water heating system, and carpenters or masonry workers to construct the pebble-bed container. Consequently, the general contractor and the solar system contractor should coordinate their activities so that each task is accomplished at the most appropriate and convenient stage during construction. Quality installation is an important requirement to obtain a high performance air heating solar system.

LIQUID HEATING SOLAR SYSTEM

A schematic diagram of a complete liquid-heating solar system for solar space heating using water as the heat transport and storage fluid is presented on the following page. The system is comprised of solar collectors, storage tank, auxiliary boiler, and pumps, valves, and heat exchangers.

The collector heat exchanger is used for systems in freezing climates to separate the antifreeze in the collector loop from the storage tank water. The heat exchanger may be a counterflow tube-in-shell type.

A central heat distribution system with a single heat exchanger coil or multiple fan coil units in different zones in the building may be used to heat the rooms. Radiant or baseboard convection heating is an alternative method for heat delivery but for satisfactory performance, higher temperatures are required than for forced air heat exchangers. The higher temperature is a disadvantage to system operation with flat-plate collectors. The auxiliary heater may be either a boiler or an air duct furnace.


BUILDING AIR
COLLECTORS
COLLECTOR HEAT EXCHANGER
WATER STORAGE TANK
DUCT COILS
SOLAR
AUXILIARY
BOILER
FUEL VALVE
LOAD PUMP
COLLECTOR PUMPS

Water Type Solar Space Heating System

NOTE: EITHER BOILER OR DUCT HEATER IS USED

Solar Water System Components and Installation

Piping may consist of either copper or high temperature (CPVC) plastic pipe and all pipes should be insulated with appropriate material such as neoprene foam at least one-half inch in thickness. Care should be taken to allow thermal expansion of the pipes, and long pipe lengths should provide more freedom for expansion than short lengths. Pipes should be sized so that water velocity does not exceed five feet per second. In the table below, recommended pipe diameters are indicated for flow rates in gallons per minute.

Select Pipe Size	Gallons per Minute	Velocity FPS	Pressure Drop per 100 feet PSI
3/8	2	3.36	6.58
1/2	4	4.22	7.42
3/4	8	4.81	6.60
1	15	5.57	6.36
1-1/4	25	5.37	4.22

Recommended Pipe Diameters for Various Flow Rates

Circulating pumps should be centrifugal type, coupled directly to motors with rotating speeds between 700 and 1700 rpm. Centrifugal pumps are recommended because the pumping pressure is limited and if valves fail to open, or the pipeline becomes clogged, there is no danger of developing excessive pressures which could burst pipes. With known flow rate and system head, pumps may be selected from stock items in catalogs, or made to specifications by pump manufacturers. Impellers of stock item pumps may be trimmed to meet the specifications. Centrifugal pumps should be located so that priming is not necessary, which could be a particular problem in a vented system or where a storage tank is underground. The pumps should be provided with at least five feet of head on the suction side.

SOLAR HEAT PUMP SYSTEMS

Heat pumps which operate on a conventional vapor compression cycle are currently one of the most efficient heating systems. The system is usually reverse cycle, thus it can be applied to both heating and cooling. Basically, in the heating mode, heat is extracted from the outside air (or some other heat sink, such as an insulated tank of water) and pumped into the space to be heated. The cooling mode is essentially the opposite. Heat is extracted from the inside air via the vapor compression cycle and pumped to the outside. Currently available units use air-to-air, air-to-water, and water-to-water cycles. They are typically powered by an electric motor which derives the compressor and pump.

In a heat pump, the heat source should be kept as close to the design temperature point as possible in order to insure proper efficiency. This presents somewhat of a problem during the winter, since ambient temperatures drop relative to inside heating temperature requirements. Then solar/thermal energy can be applied in a solar/heat pump system.

Typically, solar/heat pump systems fall under three classifications:

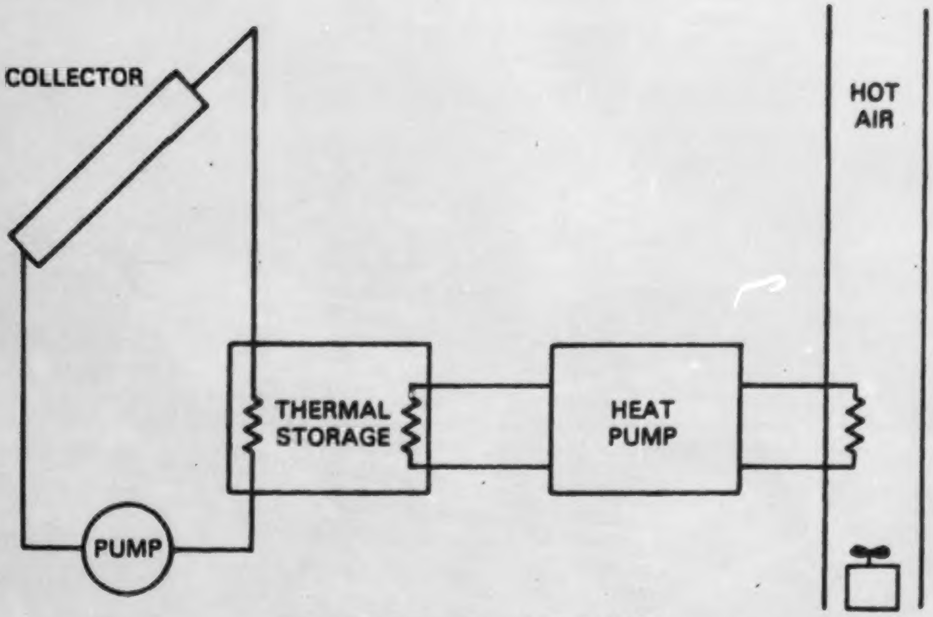
1. Solar Boosted
2. Solar Assisted
3. Solar Driven

The first two systems are illustrated schematically on the following page.

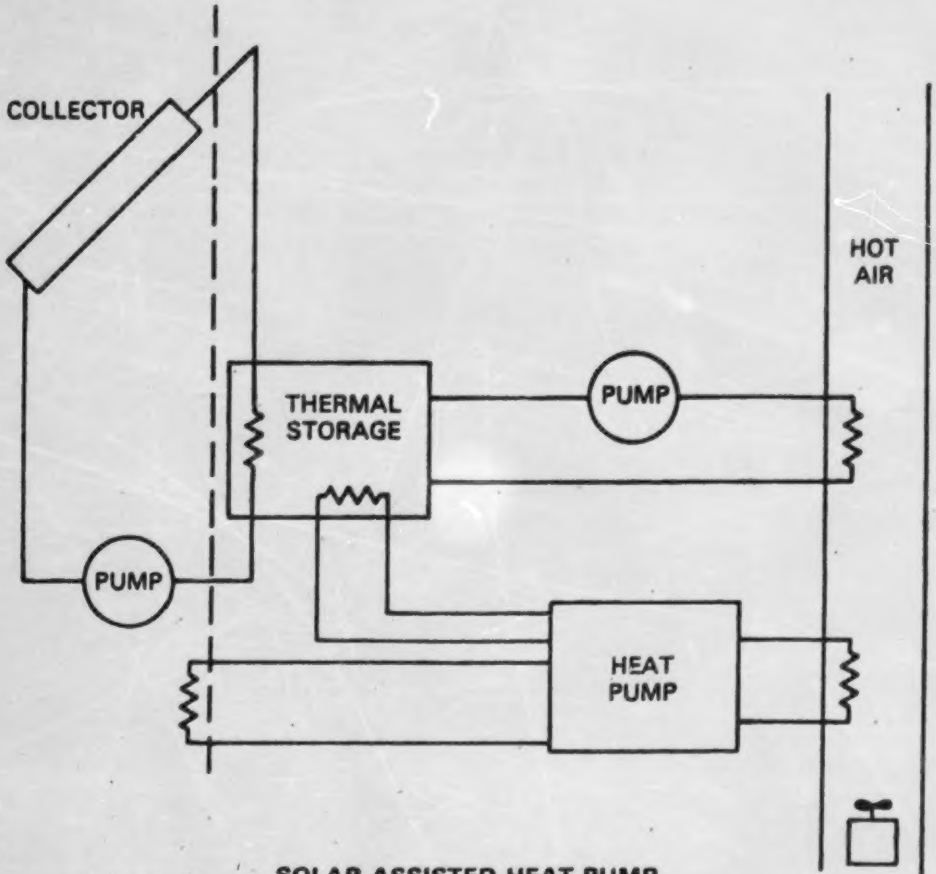
In a conventional heat pump configuration, a liquid heat exchanger which can use solar heated water is substituted for the air heat exchanger. This raises the heat source temperature relative to the ambient temperature, thus providing a solar "boost" to the conventional system hence the name "solar boosted heat pump." The solar heated fluid supplied to the heat pump unit also can come from the thermal storage system during periods of no sunlight.

The solar assisted heat pump might more aptly be called a heat pump assisted solar system. In this configuration, the heat pump is used to provide supplementary heating when the solar system and/or storage system cannot meet the heating requirements alone. In this case, the heat pump can use the relatively low (although still usually higher than ambient) temperatures of the storage unit as a heat source or it can extract heat directly from the outside environment.

The concept of a solar-assisted heat pump is to supply


COLLECTOR
HOT AIR
THERMAL STORAGE
HEAT PUMP
PUMP

SOLAR BOOSTED HEAT PUMP


COLLECTOR
HOT AIR
THERMAL STORAGE
PUMP
PUMP
HEAT PUMP

SOLAR ASSISTED HEAT PUMP

a higher temperature heat source than outdoor ambient air to the heat pump from solar collectors or storage. Typically, solar heated air or water could be 40° to 110°F above the ambient air or water temperature. Because the fluid temperature delivered from the collectors is low, greater efficiency is expected from the solar system as compared to a solar system using direct heating methods, which typically requires 150°F water temperatures above ambient. A solar heat pump system is appropriate in extremely cold, windy, or cloudy areas where flat-plate collectors could be used effectively to collect solar energy at temperatures sufficient for a heat pump.

Heat is usually stored for the low temperature side of the heat pump because it results in better system efficiency and smaller size unit than if storage is provided in the "hot side". Solar air heating collectors with a pebble-bed storage unit or liquid heating collectors with water or phase change storage may be used along with any of the three types of heat pumps available commercially.

There is not yet a clear indication of what heat pump arrangement is going to prove best. With an air system, it appears that the heat pump can be most advantageously used if operated simply as the auxiliary furnace to raise the temperature of the circulating air from the pebble-bed to the rooms. In the liquid system, whether the heat pump should be used in a similar fashion, or whether the source should be the solar storage tank, is not yet clear. At this time, an engineer and the heat pump manufacturer should be consulted to assist in the design of a solar heat pump combination.

COURSE I: SOLAR APPLICATIONS AND FUTURE TECHNOLOGY

MODULE A: SOLAR APPLICATIONS
UNIT IV: SOLAR COOLING

HANDOUT 1: TYPES OF SYSTEMS

Solar cooling may be achieved by the addition of certain components, some of which are already on the market (others are in the development stage), to a baseline solar heating system similar to those presented. Solar cooling thus implies, in most cases, a solar heating and cooling system. However, solar cooling requires significantly higher working fluid temperatures than those typically used in space heating applications. These higher temperatures can usually be attained with the use of advanced collector systems such as focusing or tubular glass collectors.

Review "Module A: Collectors" which may be found under "Course VII: Collectors and Energy Storage".

Review "Unit III: Cooling Systems" which may be found under "Module 9".

COURSE I: SOLAR APPLICATIONS AND FUTURE TECHNOLOGY

MODULE A: SOLAR APPLICATIONS

UNIT V: OTHER SOLAR APPLICATION

HANDOUT 1: GREENHOUSE

Building an attached solar greenhouse is rapidly becoming popular as a source of energy, of fresh food and/or of flowers right through the winter. A traditional greenhouse usually was constructed without much regard for the most effective use of the sun's energy. A solar greenhouse, if constructed properly, will collect solar energy efficiently, store solar energy, reduce heat loss and provide light zoning for various plants.

Greenhouses attached to residences can perform two key passive design roles:

1. as secondary skins, effectively raising the temperature just outside the building's exterior wall in the winter (and, if plants and shading devices are used, lowering it in the summer) and
2. as passive solar collectors.

For passive design purposes, these simple rules-of-thumb may be of value:

1. A greenhouse can be constructed as a secondary skin on any facade--but a south-facing greenhouse makes the best passive solar collector.

2. The wall between the greenhouse and the residence must be insulated to control heat flow and to prevent overheating.
3. Wall surfaces directly exposed to the sun should be dark-colored. Floors should be light-colored if there is danger of them becoming too warm.
4. Insulated shutters allow the greenhouse to retain the heat collected after the sun has gone down.
5. The distance from the exterior wall of the greenhouse to another object on the landscape (a tree, another building, etc.) should be at least 2½ times the height of the wall.

COURSE I: SOLAR APPLICATIONS AND FUTURE TECHNOLOGY

MODULE A: SOLAR APPLICATIONS

UNIT V: OTHER SOLAR APPLICATIONS

HANDOUT 2: PHOTO-VOLTAIC CELLS

Photo-voltaic cells are special solar collectors that change the sun's energy directly into electricity. The photovoltaic cell consists of an np junction between two different semiconductors, an n-type material in which conduction is due to electrons, and a p-type material in which conduction is due to positive holes. When light is absorbed near such a junction, new mobile electrons and holes are released causing a small electrical field at the junction, resulting in electrical energy. The current produced by short-circuiting solar cells is directly proportional to light intensity and in direct sunlight is about 28 milli-amps per square centimeter. A maximum output power of about 11 milliwatts per cm^2 at an output of .45 volts. The top efficiency of these cells is around 11%.

Typical junctions for photo-voltaic cells are:

1. Silicon--silicon boride
2. Selenium--iron
3. Copper oxide--copper

Three recent reports, one commissioned by the Federal Energy Administration, and others by Congress' Office of Technology Assessment and the President's Council on Environmental Quality, suggest major and imminent reductions in the cost of manufacturing solar electric, or photo-voltaic, cells. FEA's report is especially optimistic about the impact of simple mass production technology on the costs of well-known, single crystal, electric cells.

In 1976, 300 to 350 kilowatts of solar cells were sold at the high price of $12,000 per kilowatt. For remote power production, where transmission lines are expensive to acquire and end-use needs are not great, photo-voltaics can be economic today.

An FEA report, written by the BDM Corporation of McLean, Virginia, concludes that a cost effective purchase by the Department of Defense for 153 megawatts of remotely sited solar electric cells could bring production costs down to a level competitive with nuclear power, or better, inside of six years. Obviously such conclusions have serious implications for power companies planning expansion programs, and the report has not benefitted from wide distribution.

Silicon does not need to be as pure for solar cells as is necessary for semiconductors. Therefore, the Federal Government has made available large sums of money for the

development of a less expensive solar cell. The price of solar-cell electricity has been dropping very rapidly and should become competitive in the very near future. It is now competitive in low-electrical-demand, remote areas.

COURSE I: SOLAR APPLICATIONS AND FUTURE TECHNOLOGY

MODULE A: SOLAR APPLICATIONS

UNIT V: OTHER SOLAR APPLICATIONS

HANDOUT 3: MISCELLANEOUS

SOLAR COOKERS

There are a variety of ways to construct a solar cooker, ranging from one constructed of aluminum foil and shaped in a parabolic circle, to sophisticated cookers which utilize solar cells. The parabolic shape is important because it directs concentrated heat directly on the cooker.

SOLAR STILLS

Distilling water with solar energy is not a new happening. The concept has been used for years. American flyers in World War II used portable distillers to purify sea water. Many ocean front residents use a similar system for removing salt from sea water.

A usable still can be made by cutting three pieces of glass in a triangular shape and gluing them together with the points up. The glass is then placed over a pan of salt water resting on an insulated pad. When the unit is placed in direct sunlight, the sun will create water condensation which will be carried to the upper part of the glass by air circulation, where it can be funneled off into an outer tray. As the process continues, all the water will be condensed, leaving only a salt residue in the pan.

The University of Arizona has been a front-runner in this field and many years ago they built a desalinization plant. Later they constructed experimental farms for growing vegetables, under completely controlled conditions. Solar alcohol stills are becoming quite common.

SOLAR FARMS

A version of a massive collector field features rows of mirrors which reflect solar heat to a boiler mounted on top of a tower which acts as an absorber/heat exchanger. Large amounts of steam are generated at the tower then piped to a turbine/generator plant to produce electricity.

Another concept under consideration for mass generation of electricity is a satellite circling the earth at the equator. A satellite in synchronous orbit around the equator receives solar energy 24 hours a day, except for short periods around the equinoxes. In this orbit, a satellite receives six to ten times the amount of solar energy available in suitable terrestrial locations in the United States. The DC power generated in space by such a satellite would be beamed via microwaves to the ground and there reconverted to high voltage DC or AC power to meet base or demand load needs. Plus, such satellites could serve as communications or observation bases.

SOLAR FOOD DRIER

Many poor families lack proper nutrition because they lack a means to preserve those foods that could improve their diets. A solar drier is one item that would be reasonable in cost and yet could become an asset to the low income family anywhere in the world.

COURSE I: SOLAR APPLICATIONS AND FUTURE TECHNOLOGY

MODULE B: FUTURE SOLAR TECHNOLOGY

UNIT I: SOME PROSPECTIVE IMPROVEMENTS

HANDOUT 1: INTRODUCTION

Many of the solar systems that have been previously described are cost-effective systems that have been installed and operated. Data obtained from experimental systems indicate that they function satisfactorily in residential buildings. Fluids that are heated by solar energy in flat-plate collectors are sufficiently high in temperature to heat space and hot water and to provide the hot water to drive an absorption cooling machine. Although efficiencies of the systems vary, they are usually about 30 percent and, while such an efficiency is satisfactory, if it can be improved by better components at lower energy cost, the improvements are useful. A number of new features and components of systems are being researched and many could improve system performance significantly.

Flat-plate collectors can be improved with selective coatings or redesigned to provide greater efficiencies in heat collection, Storage with latent heat materials could furnish greater heat capacity in more compact space, and storage for liquid systems with direct contact heat exchanger to eliminate some hardware would improve system performance. If conditioning equipment using solar-heated air could be developed, the air-heating solar systems could be used throughout the year for heating and cooling. These and many other future prospects are in store for solar heating and cooling systems.

COURSE I: SOLAR APPLICATIONS AND FUTURE TECHNOLOGY

MODULE B: FUTURE SOLAR TECHNOLOGY

UNIT I: SOME PROSPECTIVE IMPROVEMENTS

HANDOUT 2: COLLECTORS

The major component in a solar system which could improve performance is the solar collector. Improvements which will increase efficiency of energy collection and decrease the delivered costs are particularly worthwhile. Among many interesting possibilities are the addition of selective surfaces to absorbers, and collectors with the air evacuated from around the absorber plates to decrease heat losses and improve collector efficiency.

Selective surfaces have high absorptance of solar radiation and low emittance of long-wave radiation. There are a variety of selective surfaces that could be used in flat-plate collectors, and some are being tested on experimental units. A number of coatings such as copper oxide and black nickel have been available for a long time, but technical problems and cost have limited their use. Black chrome seems to hold some promise and some flat-plate collectors are presently available with such absorber coatings.

Characteristics of some selective surfaces are listed in the following table.

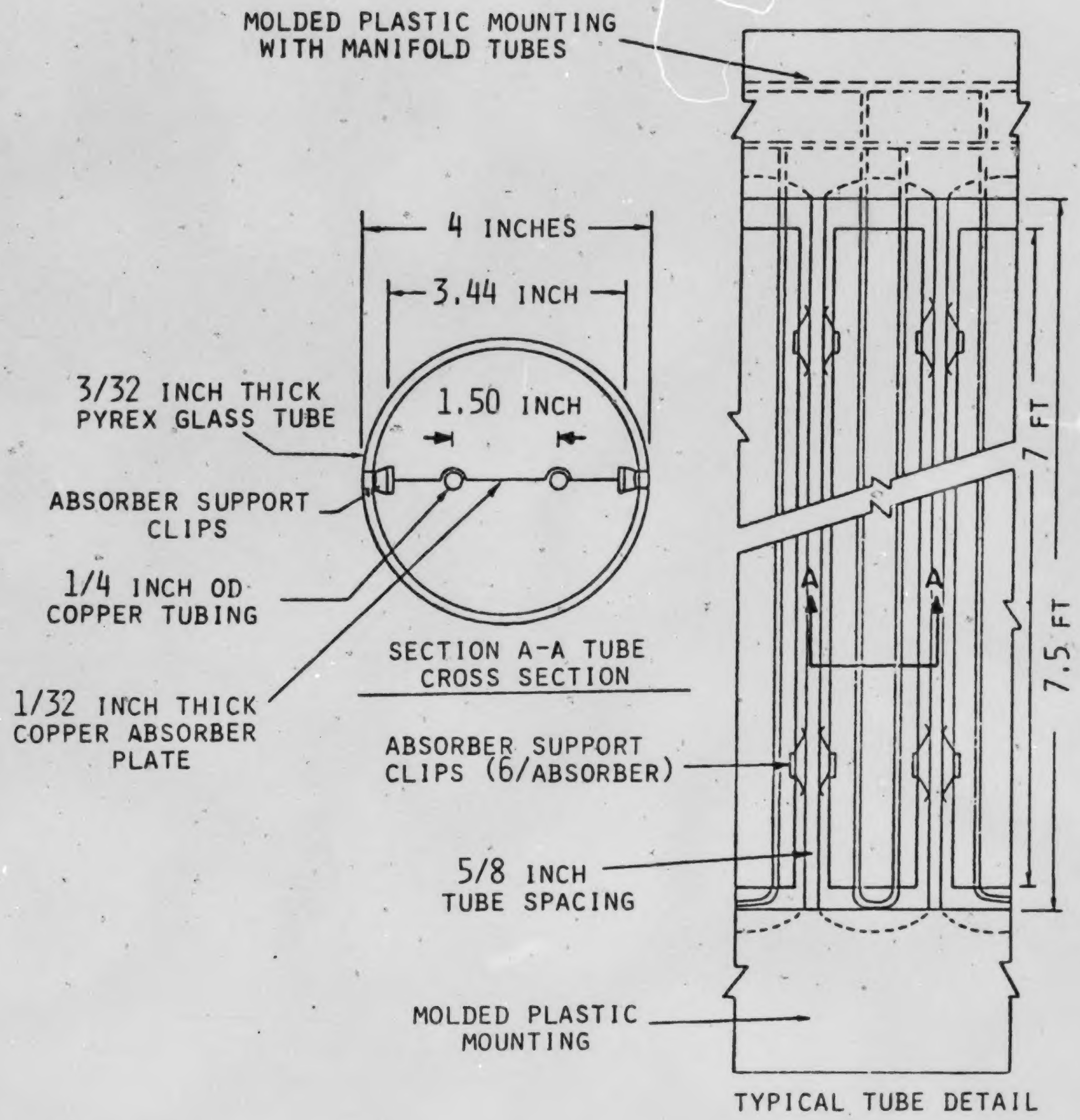
SELECTIVE SURFACES CHARACTERISTICS

Coating	Absorptance	Emittance
Converted Zinc	0.90	0.071
Black Nickel	0.88	0.066
Black Chrome	0.92	0.085

EVACUATED-TUBE COLLECTORS

Evacuation of the air around the absorber plate is potentially a significant improvement in solar collectors. There are a number of different designs that are being assembled and tested, and at least one manufacturer makes them in moderate quantities. Evacuated collectors will produce more useful heat than standard flat-plate collectors under equal sun and weather conditions because the losses from the absorber are greatly reduced. With a vacuum surrounding the absorber, conduction and convection losses are effectively negligible and, if the absorber coating is a selective surface, the radiation loss is small.

One design, by Corning Glass Works, is shown on the following page. Inside an evacuated glass tube which is four inches in diameter is a copper absorber plate with a selective surface.

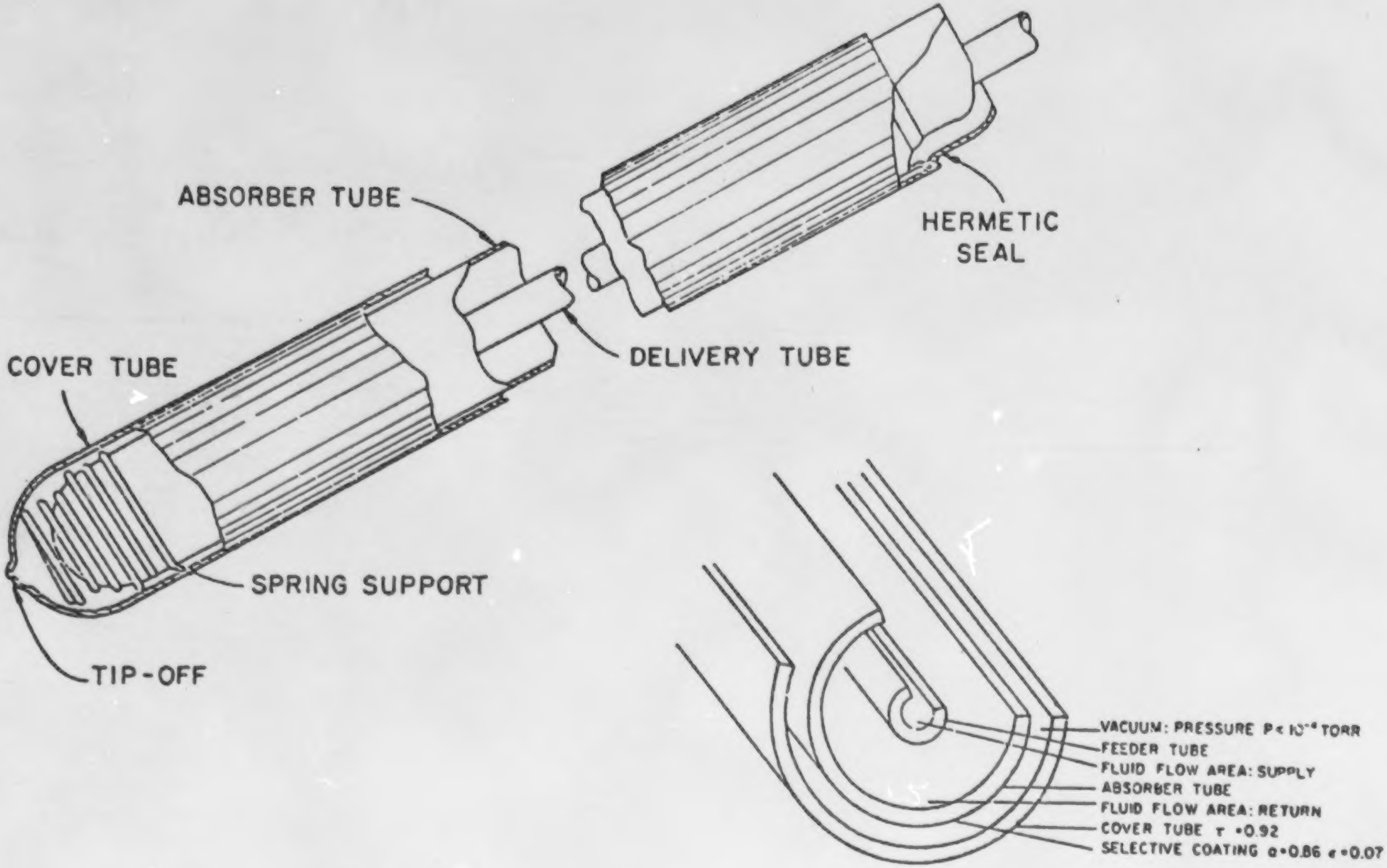

MOLDED PLASTIC MOUNTING WITH MANIFOLD TUBES
4 INCHES
3.44 INCH
1.50 INCH
3/32 INCH THICK PYREX GLASS TUBE
ABSORBER SUPPORT CLIPS
1/4 INCH OD COPPER TUBING
1/32 INCH THICK COPPER ABSORBER PLATE
SECTION A-A TUBE CROSS SECTION
7 FT
7.5 FT
A
A
ABSORBER SUPPORT CLIPS (6/ABSORBER)
5/8 INCH TUBE SPACING
MOLDED PLASTIC MOUNTING
TYPICAL TUBE DETAIL

Corning Glass Company Evacuated Tube Collector

Bonded to the plate is a copper U-tube which carries the heat transfer fluid. The ends of the tube protrude through one end of the glass tube, and the absorber plate is free to expand toward the other end. The efficiency range of the collector varies from about 74 percent when the inlet fluid temperature is low to about 60 percent when the fluid is near the boiling temperature of water. Most flat-plate collectors have high efficiency with low inlet fluid temperatures, but have low efficiencies when the fluid temperature is near boiling. The evacuated tube collector has a significant advantage when producing high temperature heat to the system and can be used effectively with solar cooling units where high temperature fluid is needed.

An evacuated tube collector design by the Owens-Illinois Glass Company is shown on the following page. There are three concentric glass tubes with the middle one coated with a black selective surface. The vacuum is between the outer and middle tubes. Fluid is transported through the inner tube and, as it passes through the annulus in contact with the absorber tube, heat is transferred from the glass to the fluid.

Two other evacuated tube collectors are being experimentally tested, one by the General Electric Company for use in air-heating systems and another is by the Philips Company in West Germany for liquid systems. Many variations in design of evacuated tube collectors are possible, and different designs will gradually advance to the practical stage.


ABSORBER TUBE
HERMETIC SEAL
DELIVERY TUBE
COVER TUBE
SPRING SUPPORT
TIP-OFF
VACUUM: PRESSURE $P < 10^{-4}$ TORR
FEEDER TUBE
FLUID FLOW AREA: SUPPLY
ABSORBER TUBE
FLUID FLOW AREA: RETURN
COVER TUBE $\tau = 0.92$
SELECTIVE COATING $\alpha = 0.86$ $\epsilon = 0.07$

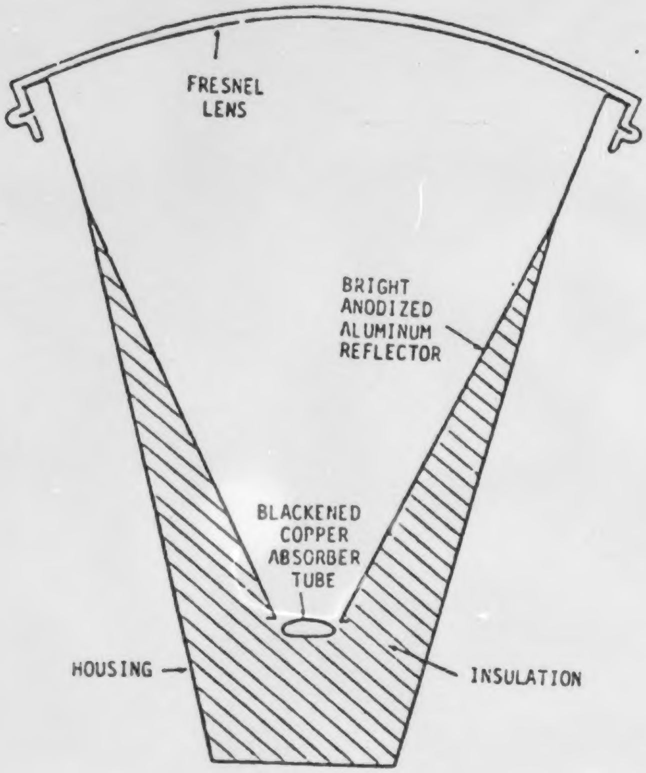
Schematic of the Owens-Illinois Evacuated Tube Solar Collector

CONCENTRATING COLLECTORS

Concentrating collectors are sometimes called focusing collectors or tracking collectors. The sun's radiation is reflected off one or more mirrors to concentrate it onto a very small absorber area. Most concentrating collectors require mechanical devices to shift the collector position and track the sun in its travel across the sky. Some require special optical lens arrangements to help focus the sun's energy.

Concentrating collectors are used when very high temperature fluid is needed to drive heat engines or to be used in industrial processes. If concentrating collectors can be designed to be more efficient than flat-plate collectors, operate reliably, and with little maintenance so that the cost of delivering energy is low, then such collectors can have potential uses in residential solar systems. Experience thus far has indicated otherwise, but there is considerable research under way and new designs for concentrating collectors are being developed.

One type of low concentration collector is being developed by the Northrup Company and is being tested on a number of solar systems for large buildings. A linear focusing collector with a Fresnel lens is the type being developed and is shown below. The collector is mounted with the axis on the north-south direction and tilted at an angle with respect to the horizontal plane. The collector rotates from east to west during the day so that the direct rays from the sun are focused into the absorber tube. A distinct disadvantage of concentrating collectors is that only the direct rays from the sun are used, as the diffuse radiation cannot be focused.


FRESNEL LENS
BRIGHT ANODIZED ALUMINUM REFLECTOR
BLACKENED COPPER ABSORBER TUBE
HOUSING
INSULATION

Fresnel Lens Strip Solar Collector

COURSE I: SOLAR APPLICATION AND FUTURE TECHNOLOGY

MODULE B: FUTURE SOLAR TECHNOLOGY

UNIT I: SOME PROSPECTIVE IMPROVEMENTS

HANDOUT 3: STORAGE

A sizable amount of research is being devoted toward the utilization of salt hydrates and other phase-change materials for storage of latent heat. The main difficulties are packaging the storage material and stratification or separation of the material after a few hundred cycles of phase changes. One advantage in the use of phase change materials is supposedly the smaller storage volume needed, as compared to water or rocks. However, a solar heating and cooling system requires a water volume of only two gallons of water or one-half cubic foot of rocks per square foot of solar collector area and, in a typical system with 500 square feet of collectors, the water volume needed is about 1000 gallons or about 350 cubic feet of rocks. When packaged phase-change material is placed in a container with adequate surface contact with the heat transfer fluid from the collectors, it is difficult to achieve a significantly smaller volume of storage.

With proper materials there is, however, an advantage in being able to obtain a sustained constant temperature of the heat delivered from storage. This property of latent heat storage materials can be used to an advantage in solar cooling systems, both in the hot storage and cold storage tanks.

Another future prospect for storage of thermal energy is in chemical methods. Chemical storage offers technical possibilities that sensible and latent heat storage do not. These possibilities include:

1. long-term storage without need for insulation and without thermal loss
2. storage at high energy density
3. recovery of stored thermal energy at temperatures above or below the original temperature.

Although no thermo-chemical system appears imminent, in concept at least, this method of storage can have important applications in terms of supply and demand and improving thermal efficiency.

COURSE I: SOLAR APPLICATIONS AND FUTURE TECHNOLOGY

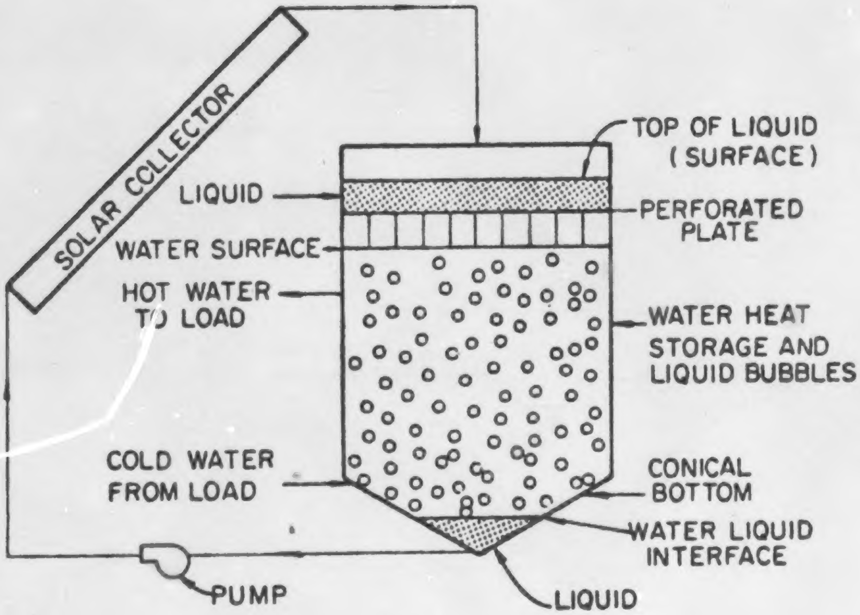
MODULE B: FUTURE SOLAR TECHNOLOGY

UNIT I: SOME PROSPECTIVE IMPROVEMENTS

HANDOUT 4: HEAT EXCHANGER

The disadvantage of a heat exchanger in present liquid-heating solar systems is the temperature difference needed to transfer the heat at the heat exchanger. A temperature difference of 10 to 20°F has a significant influence on the amount of useful heat delivered by the system. The temperature in storage is low and the collector efficiency is less.

A heat exchanger-storage combination unit is under investigation where heat is transferred from liquid droplets that transport heat from the collector to water in the storage tank. A liquid that is immiscible in water is pumped through the solar collector and through the storage tank as droplets. If the density of the liquid is substantially different from that of water, the liquid droplets will either rise or descend through the water in the storage tank. A schematic of a heat exchanger-storage unit is shown on the following page. For the illustration shown, the liquid is heavier than water. The liquid is delivered to the top of the tank, is broken up into droplets at the perforated plate, and collects in the bottom cone. The temperature difference between the droplets and the storage water is only about 1°F or less, with substantial heat transfer occurring across the large collective area


SOLAR COLLECTOR
LIQUID
WATER SURFACE
HOT WATER TO LOAD
COLD WATER FROM LOAD
PUMP
TOP OF LIQUID (SURFACE)
PERFORATED PLATE
WATER HEAT STORAGE AND LIQUID BUBBLES
CONICAL BOTTOM
WATER LIQUID INTERFACE
LIQUID

Direct Contact Liquid-Liquid Heat Exchanger

PROPERTIES OF POSSIBLE COLLECTOR FLUIDS

Fluid	Freezing Point (°F)	Boiling Point (°F)	Specific Gravity	Cost ($/gal)
1	-31	698	1.116	2.98
2	-36	734	1.208	6.91
3	-31	644	1.048	3.32
4	-41	568	1.120	3.46
5	-27	415	1.043	10.45
6	-13	770	1.162	8.63
7	-76	782	0.927	3.79
8	-67	478	0.913	9.80

of the droplets. There are several possible liquids that can be used and, although not named, their properties and approximate costs are listed directly above.

COURSE I: SOLAR APPLICATIONS AND FUTURE TECHNOLOGY

MODULE B: FUTURE SOLAR TECHNOLOGY

UNIT I: SOME PROSPECTIVE IMPROVEMENTS

HANDOUT 5: MISCELLANEOUS

As of now the only commercially available cooling unit in small size that is operable with solar energy is a lithium-bromide absorption cooling unit. As mentioned elsewhere, there are a number of different experimental cooling units that are being developed, such as the heat engine-driven refrigeration machine and ammonia-water continuous cycle unit.

There is also considerable effort being made in the development of so-called total energy systems, where high temperature heat from solar energy is used to generate electricity and the low temperature "waste" heat is used to heat and cool a cluster of buildings. Such systems are likely destined for specialized use in grouped facilities such as military bases but, with some variation, may serve a number of homes or apartment complexes.

In long term, development of photovoltaic systems for residential buildings is a possibility. Electricity that is generated could operate the heating and cooling system in the house. Whether photovoltaic systems will ever be low enough in cost to be competitive with electricity generated from fossil or nuclear fuels is an open question, but a significant amount of effort is being devoted to improve efficiency and reduce the costs.

Other improvements in systems which utilize solar energy are hybrid systems consisting of passive and active components. There has not been much effort toward development of passive systems except by architectural treatment of windows. While this effort has been significant, more direct heating of residential space with passive systems may minimize the size of the active components and thereby reduce overall costs.

One company manufactures a transparent insulation that could change the way windows are made. They call it a heat mirror. Its film cuts thermal conductivity by as much as 60% but lets visible light travel through.

A snow pack is a large block of ice which is made during a northern winter. It is used to provide air-conditioning in the hot summer, then to take heat out of the resulting warm water in the next winter to provide residential heating and thus recreate the ice block. Solar assist.

Big fin (zomeworks) is a long fin press-fitted to copper pipe and plumbed into a hot water storage tank. It can be placed at windows in sun rooms, greenhouses, and other sun-exposed spaces that do not freeze. It can utilize natural convection or water can be pumped.

PREREQUISITES: SOLAR ENERGY TECHNICIAN

1. The student must have the ability to use small machine and hand tools (electric drill, saw, pliers, hammers, and chisels).
2. The student must be able to weld, or learn how to weld.
3. The student must be able to lift 100 lbs over his/her head.
4. The student must be able to read at the fifth-grade level.
5. The student must be able to work in environments of extreme cold and hot climates, from -20° to +98°F.
6. The student must be able to work in close confines.
7. The student must be physically fit and cannot have physical handicaps of the type that would restrict the student from job duties. A student must be able to work on the roof of a house or apartment without getting dizzy.
8. The student must be able to be bonded.
9. The student should have an interest in air conditioning (HVAC) and/or plumbing.
10. Student should be interested in solar as an alternate source of energy.
11. A high school diploma or GED equivalency is desired but not required.
12. Assume knowledge of basic arithmetic operations, including addition, subtraction, multiplication, and division. Must be able to read charts.
13. Normal color vision is desired, but not essential.

COURSE IV: INTRODUCTION TO SOLAR ENERGY

MODULE A: THE SUN AND RADIATION

MODULE DESCRIPTION:

Solar energy starts, of course, with the sun. The sun is a huge nuclear fusion reactor located at an average distance of 93 million miles from earth. It has a surface temperature of about 10,800°F, and gives off energy continuously in the form of radiation. The use of the energy which reaches earth for heating and cooling is what this course is all about. In this module you will learn about the way the energy given off by the sun is altered before it reaches the earth and the amount of energy that reaches earth.

GOAL STATEMENT:

Many factors affect the amount of solar energy that reaches the earth's surface. Knowledge of these factors is essential to the proper design and understanding of all solar systems.

COURSE IV: INTRODUCTION TO SOLAR ENERGY

MODULE A: THE SUN AND RADIATION

UNIT I: Solar Concepts A-2

Handout 1: Introduction, the Sun and Solar Energy Units A-2

2: Factors Affecting the Path of Radiation Through Atmosphere A-8

MODULE B: SOLAR ENERGY COLLECTION

UNIT I: Introduction B-1

Handout 1: Basic Principle B-1

2: Comparison of Collectors B-3

UNIT II: Types of Solar Collectors B-5

Handout 1: Flat-Plate Collectors B-5

2: Evacuated-Tube Collectors B-12

3: Concentrating Collectors B-16

4: Photo-Voltaic Cells B-18

MODULE C: SOLAR ENERGY STORAGE

UNIT I: Introduction C-1

Handout 1: Types of Storage C-1

2: Storage Location, Size, and Heat Loss C-4

UNIT II: Water and Rock Storage C-7

Handout 1: Introduction to Water Storage C-7

2: Introduction to Rock Storage C-10

MODULE D: SOLAR SYSTEMS

UNIT I: Introduction to Solar Systems D-1

Handout 1: Active Systems D-1

2: Building Design and the Passive System D-6

MODULE E: FUTURE OUTLOOK FOR SOLAR

UNIT I: Barriers and Incentives E-1

Handout 1: Barriers E-1

2: Incentives E-7

UNIT II: Solar Economics E-11

Handout 1: Solar Costs E-11

COURSE IV: INTRODUCTION TO SOLAR ENERGY

MODULE A: THE SUN AND RADIATION

UNIT I: SOLAR CONCEPTS

UNIT OBJECTIVE

Upon completion of this unit the student will be able to discuss the sun and its production of energy, the magnitude of energy reaching the outer atmosphere and the disposition of that energy.

SPECIFIC OBJECTIVES

Upon completion of this unit the student will be able to:

1. Recognize the magnitude of solar energy available from the sun and units of solar intensity.
2. Recognize the effect of atmospheric conditions, seasonal, and daily variations have on the amount of energy reaching the earth.

COURSE IV: INTRODUCTION TO SOLAR ENERGY

MODULE A: THE SUN AND RADIATION

UNIT I: SOLAR CONCEPTS

HANDOUT 1: INTRODUCTION, THE SUN AND SOLAR ENERGY UNITS

The sun provides, directly and indirectly, virtually all energy used on this earth. All life depends on the sun and its rays. All fossil fuels got their energy from the sun through life processes many years ago.

We can get some idea of the huge amount of energy that arrives from the sun by expressing it in various ways. For instance, suppose we were to take all the known or estimated deposits of coal and oil and burn them so as to give energy at the same rate as that supplied by the sun. We would use up these deposits completely in three days.

Although the sun is 93 million miles away, we know a surprising amount about it. The sun's diameter is approximately 865,000 miles. That is about 109 times the diameter of the earth. Its mass is 333,000 times that of the earth. If sun and earth were made of the same material, the sun would have a mass of a million times that of the earth. Thus, it is apparent that the sun's average density is only about one-third that of the earth. In fact, the sun is not a mass of rock and metal like the earth. The sun, instead, consists almost entirely of the element hydrogen, with around one percent of heavier element.

Conditions at the sun's center are almost unimaginable. The temperature there is up to about 20 million degrees Fahrenheit, and the pressure due to gravity is about one billion tons per square inch. Under such colossal pressure, the atoms of hydrogen (on earth, the lightest of all gases) are packed together so tightly that their density is about ten times that of lead. Four protons combine to form the nucleus of a new element, helium. This regrouping of protons is not, however, a simple joining up of existing particles. There is a slight loss of mass. $E = Mc^2$.

What goes on inside the sun is a fusion of hydrogen to helium. The loss of mass is the direct cause of the sun's outpouring of energy. The energy output of the sun requires the burning or conversion of mass into energy at the rate of 4.2 million tons per second. The thermonuclear fusions at the core of the sun release energy in the form of high-frequency electromagnetic radiation. The theory which currently is most accepted states that electromagnetic radiation can be represented as either a combination of rapidly alternating electric and magnetic fields (or waves) or energy particles called photons. This definition of radiation is difficult to understand and visualize but the theory behind it allows us to describe and predict how radiation will act. Radiant energy is produced at the solar core at temperatures estimated between 18,000,000° to 25,000,000° Fahrenheit. The average temperature at the surface of the sun is only 10,000°F.

Experiments with hydrogen bombs show that much of the energy of fusion generates short radiation waves called x-rays and gamma rays. Because these waves are so short, they have a very high concentration of energy. They are therefore able to penetrate, for example, thick walls of concrete. Rays of this sort are deadly. If the earth received the full force of this radiation from the sun, life would be impossible. But the outer layers of the sun act as an energy converter. The gases of these layers are heated by the short waves; in turn, the gases give out radiations mostly of longer wave length--that is ultraviolet, visible light and the longer waves of infrared or heat.

At an average temperature of 10,000°F, the sun radiates most of its energy at very high frequencies (short wavelengths). Visible light makes up 46% of the total energy emitted from the sun. Visible light, or the wavelength to which the human eye is sensitive, extends from 0.35 to 0.75 microns (the unit used to measure wavelength is the micron or micrometer which is equal to a millionth of a meter or .00004 of an inch). It is made up of all the familiar colors from the shorter wavelength violet (0.35 microns) to blue, green yellow, orange and the longer wavelength red (0.75 microns). Forty-nine percent of the radiation emitted from the sun is in the infrared (below red) band. Infrared radiation, which we experience as heat, is radiation at wavelengths longer than the red end of the visible spectrum (greater than 0.75 microns). The remaining portion of the sun's radiation is emitted in the ultra-violet band at wavelengths shorter than the violet end of the visible spectrum (smaller than 0.35 microns). All electromagnetic radiation leaving the sun travels through space at a uniform rate, in the form of diverging rays, traveling at the speed of light which is 186,280 miles a second (300,000 kilometers a second). The earth, a small body compared to the sun, intercepts such a small part of the sun's radiant output that the sun's rays are assumed to be a parallel beam. At a distance of 93 million miles from the sun, the earth intercepts approximately 2 billionths of the sun's radiant output or the equivalent of about 35,000 times the total energy used by all people in one year.

The Solar Constant, which defines the amount of radiation or heat energy reaching the outside of the earth's atmosphere, is 429.2 BTUs per square foot per hour (1.94 calories per square centimeter per hour). In other words, if we located a square foot of material just outside the earth's atmosphere and perpendicular to the sun's rays, it would intercept 429.2 BTUs of energy each hour. There are slight variations in the numerical value of the Solar Constant because, while the earth's orbit around the sun is almost perfectly circular, within this orbit the sun is slightly off center. This difference is important to scientists doing detailed calculations out in space but on the earth's surface the variation is so slight it has little effect on the solar heating of buildings.

The intensity of solar energy is found expressed in several different units. In this course only one unit will be used, BTU/ft^2. However, you may often find other units when looking for solar data, so it is worthwhile to learn to recognize these units and to be able to convert from one unit to another. Units commonly found are listed below.

ABBREVIATION	UNIT
Energy Density	
BTU/ft^2	British Thermal Units per square foot
KJ/m^2	Kilojoules per square meter
Langley (cal/cm^2)	calories per square centimeter
Power	
BTU/ft^2·hr	British Thermal Units per square foot per hour
KJ/m^2·hr	Kilojoules per square meter per hour
Langley/min	calories per square centimeter per min.
W/m^2	Watts per square meter

TO CONVERT INTO BTU/FT^2	
Multiply	By
Langleys	3.69
KJ/m^2	.088

TO CONVERT INTO BTU/FT^2·HR	
Multiply	By
Langleys/min	221
KJ/m^2·hr	.088
W/m^2	.316

COURSE IV: INTRODUCTION TO SOLAR ENERGY

MODULE A: THE SUN AND RADIATION

UNIT I: SOLAR CONCEPTS

HANDOUT 2: FACTORS AFFECTING THE PATH OF RADIATION THROUGH THE ATMOSPHERE

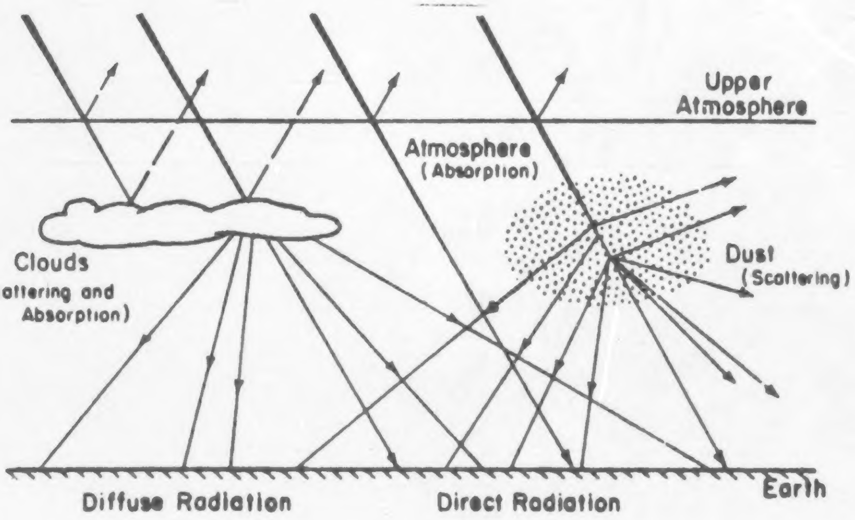
Direct and Diffuse Radiation

The energy reaching earth is reduced from the "outer space" intensity. There are a number of processes that occur in the atmosphere that cause this reduction. Some of the energy is reflected back into outer space by the top of the atmosphere, much as light is reflected from a mirror. Still more is reflected from the tops of clouds. As much as 30 percent of the incoming radiation is reflected in this manner. A portion of the radiation is absorbed by chemical compounds in the atmosphere. The ozone layer absorbs much of the ultraviolet radiation, and carbon dioxide, oxygen, and water vapor also absorb radiation. The various processes serving to reduce the solar energy reaching the earth are illustrated on the following page.

The solar constant is the solar radiation received per unit of time on a unit area of surface above the atmosphere and perpendicular to radiation at mean distance from the sun. It is equal to: 1353 watts per sq. meter

428 BTU per sq. ft. per hr.

The solar energy striking the outer atmosphere varies throughout the year from about 410 to 440 BTU per sq. ft. per hr., because of the variation of distance of the earth from the sun.


Upper Atmosphere
Atmosphere (Absorption)
Clouds (Scattering and Absorption)
Dust (Scattering)
Diffuse Radiation
Direct Radiation
Earth

Atmospheric Effects on Solar Radiation Reaching Earth

Solar radiation reaches the earth's surface either as direct radiation or as diffuse radiation. Direct radiation is that portion of the radiation beamed directly from the sun. Diffuse radiation comes from scattering of sunlight by the clear sky; scattering by haze, pollution, or humidity; or transmission through clouds.

The radiation reaching the earth's surface is substantially less than that reaching the outer atmosphere. Even on a clear day, direct and diffuse insolation may be only 75% of that reaching the outer atmosphere.

On a sunny or hazy day, major part of solar radiation reaches the earth's surface as direct radiation. During hazy periods, when the sun still casts a shadow, as little as 50% of the clear day insolation may be striking the surface.

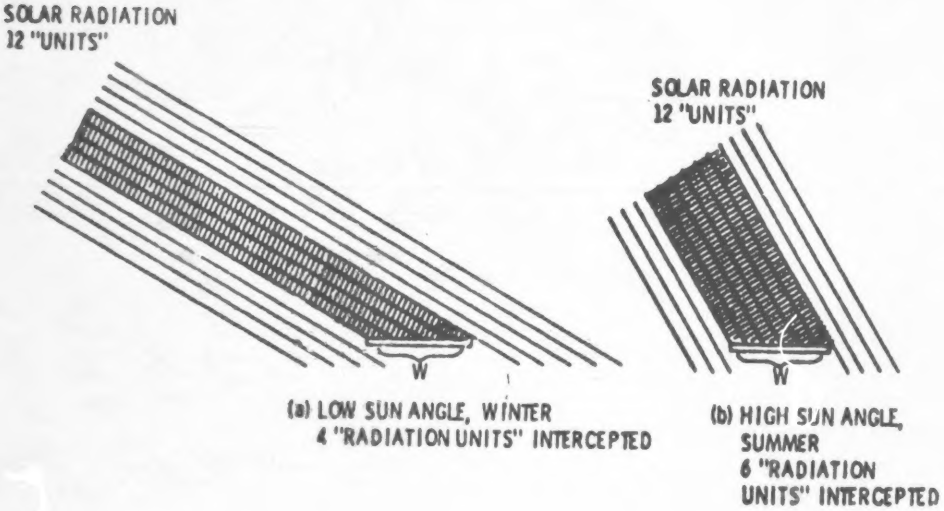
During periods of total cloudiness, the total insolation is much less, but up to 20 percent of the clear day insolation may still be hitting the surface.

Radiation may be reflected into collector from ground surfaces, snow, and adjacent building surfaces. Ground reflection depends to quite an extent on the shape and texture of the surroundings and the altitude of the sun. Snow reflects more sunlight than grass, and more reflection occurs when the sun is lower in the sky.

Monthly Variations

Solar energy on a horizontal surface at any location on earth, if averaged over a month, shows a month-to-month variation. This is due both to seasonal changes in weather, which affect the cloud cover, and the changing angular relationship between the sun and the surface. In the winter the sun is lower in the sky than in the summer, and the resultant larger angle between the sun and a horizontal surface reduces the amount of radiation intercepted by the surface.

The illustration (a) below shows the energy intercepted by a unit width horizontal surface when the sun is at a low angle. In illustration (b) the sun is shown at a higher angle and a larger amount of energy is intercepted.


SOLAR RADIATION 12 "UNITS"
W
(a) LOW SUN ANGLE, WINTER 4 "RADIATION UNITS" INTERCEPTED
SOLAR RADIATION 12 "UNITS"
W
(b) HIGH SUN ANGLE, SUMMER 6 "RADIATION UNITS" INTERCEPTED

Energy Intercepted by a Unit-Width Horizontal Surface

The monthly variations in energy on a horizontal surface are shown in a table, on the following page, for selected cities in the United States.

Monthly Variations in Energy on a Horizontal Surface
Selected Cities, (U.S.) (BTU/ft^2·day)

City	December	March	June	September
Chicago, Illinois	280	835	1685	1152
Tucson, Arizona	1122	1987	2572	2098
Washington, D.C.	611	1266	1818	1380
Miami, Florida	1163	1800	1958	1619
Fairbanks, Alaska	22	784	1855	662
Los Angeles, California	887	1730	2193	1851

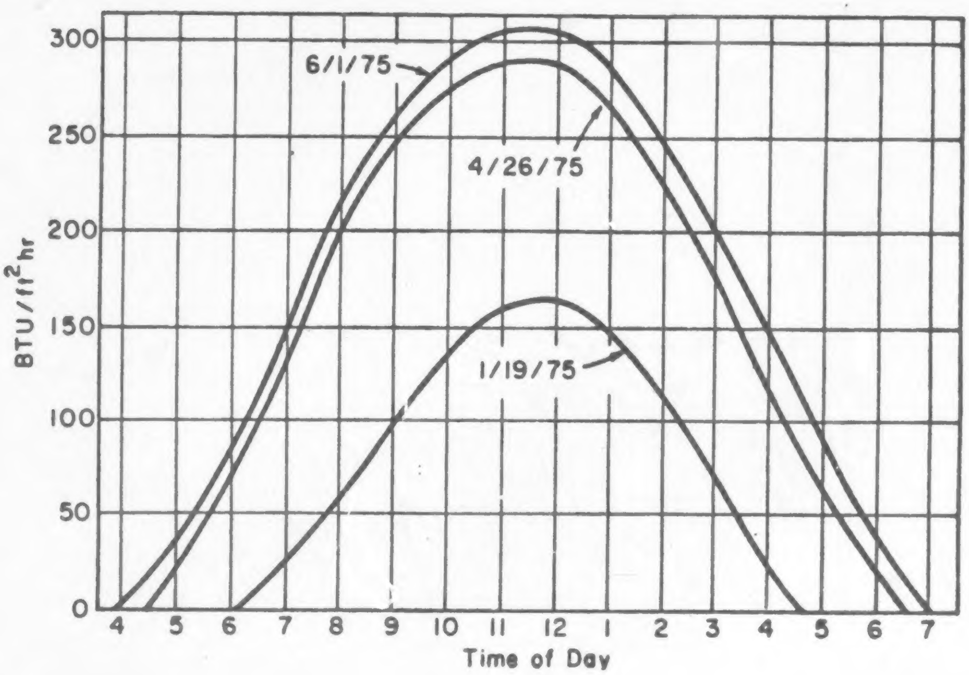
Daily Variations

The radiation reaching a horizontal surface varies from day to day, mostly due to atmospheric phenomena. Clouds, dust, and pollution can result in changes in the radiation received. Daily variations affect the performance of a solar system but the system can be designed on the basis of average conditions. For a heating system design, the average daily value for the coldest month, usually January, is of particular interest.

Hourly Variations

Hourly variations in available solar energy at a given location are due to the earth's rotation. Early morning sun is at a very low angle and the solar rays must pass through a large thickness of atmosphere. The intensity of the energy received is therefore low. The hourly peak in radiation occurs at noon, when the sun is at the highest angle and is passing through the minimum thickness of the atmosphere. Since winter days are shorter than summer days, the period during which solar energy can be collected varies with season.

The solar intensity on a horizontal surface, measured in Fort Collins, Colorado is shown on the following graph.



Hourly Record of Clear Day Radiation of a Horizontal Surface at Fort Collins, Colorado (Data from Solar House I)

The smooth curves indicate that these date were obtained on clear days. The presence of clouds would result in breaks in the curves. Note the higher intensity and longer period of measurable radiation during a summer month as opposed to a winter month.

Effects of Elevation

Direct-beam solar energy availability tends to increase with the elevation of the site because of the reduced air through which the radiation must travel.

A rough estimate of the effect of altitude on solar insolation can be arrived at by dividing the atmosphere into two layers, upper and lower. Some portions of the sun's radiation are rapidly absorbed by the upper layer. The lower layer absorbs the remaining radiation proportional to the air mass through which the sun's rays must travel. The problem essentially reduces to a calculation of the air mass at a particular altitude.

COURSE IV: INTRODUCTION TO SOLAR ENERGY

MODULE B: SOLAR ENERGY COLLECTION

UNIT I: INTRODUCTION

HANDOUT 1: BASIC PRINCIPLES

The most important component in a solar system which could improve performance is the solar collector. Improvements which will increase efficiency of energy collection and reduce the delivered costs are particularly worthwhile. Among many interesting possibilities are the addition of selective surfaces to absorbers, and collectors with the air evacuated from around the absorber plates to reduce heat losses and improve collector efficiency.

A solar collector is a means of intercepting incident solar radiation, converting this radiation to heat, and delivering useful energy to the system. A collector consists of an absorber plate, commonly a black metal surface, which absorbs the incident solar radiation and converts this solar energy to heat. A portion of this heat is transferred to a fluid and then transported to another part of the system. In the process of collecting energy and transferring the heat, the absorber plate will lose some of the heat to its surroundings, so other components of the solar collector are provided to reduce the heat losses.

Heat is lost from the absorber plate by radiation, convection, and conduction. Insulation beneath the absorber reduces the heat loss through the back of the collector, and the transparent covers reduce the heat losses from the "front" of the collector. A glass cover, which is opaque to the thermal radiation emitted by the plate, will reduce convection losses to the outside air because the air space between the absorber plate and cover restricts convective air motion.

The useful energy from a solar collector is transferred to a fluid and delivered directly to the building or to storage, where it can be used at a later time. The two principal types of fluid heating solar collects are liquid-heating solar collectors and air-heating solar collectors. Liquid heating collectors normally use water or a solution of water and ethylene glycol, antifreeze, but numerous other liquids can be used.

COURSE IV: INTRODUCTION TO SOLAR ENERGY

MODULE B: SOLAR ENERGY COLLECTION

UNIT I: INTRODUCTION

HANDOUT 2: COMPARISON OF COLLECTORS

A solar collector is a device used to collect solar radiation (energy) and to change it into usable heat. There are four types of collectors currently in use. The three most common types are flat-plate collectors, evacuated-tube collectors, and concentrating or tracking collectors.

Because of certain cost and performance advantages, the flat-plate collector is the workhorse of the solar energy industry. It has been used successfully for many years, on more solar energy systems than any other type of collector. Various designs of flat-plate collectors are currently manufactured by more than 175 companies.

In contrast, evacuated-tube collectors, photo-voltaic collectors and concentrating collectors have seen limited use. The necessary technology has just recently become economically feasible from a small number of manufacturers. For the most part, these collectors will not see the widespread application seen with flat-plate collectors.

The following sections will outline the operation and construction features of the three types of collectors:

Air collectors provide heated air at temperatures from 80°F to 180° or 200°F. With pumps not working, liquid temperatures may exceed boiling point of water or anti-freeze.

Air-heating solar collectors are less efficient than liquid collectors for the same inlet temperature, however, system efficiency is comparable. The air systems are not subject to overheating and corrosion but they do require larger ducting and storage components.

Flat-plate solar collectors absorb both direct and diffuse solar radiation. This is an important aspect of collectors, especially in areas where a large proportion of solar radiation is in the form of diffuse or reflected radiation. Flat plate collector's components are metal frame, glass cover or covers, absorber plate, piping or ducting, and bottom insulation. Typical size of collector is 3 ft. x 6 ft. x 7 in. Liquid-collector volumetric flow rate: typically 0.02 gpm per sq. ft. of collector area. Air collector flow rate: 2 cfm per sq. ft. of collector area.

Concentrating collectors produce higher output temperatures, but must track sun, and are useful only for direct radiation, not diffuse.

Evacuated tubes produce higher output temperatures, achieve higher efficiencies.

COURSE IV: INTRODUCTION TO SOLAR ENERGY

MODULE B: SOLAR ENERGY COLLECTION

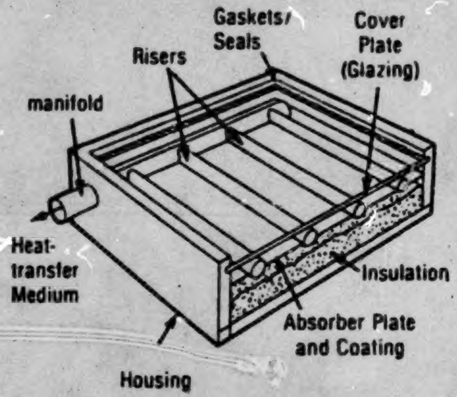
UNIT II: TYPES OF SOLAR COLLECTORS

HANDOUT 1: FLAT-PLATE COLLECTORS

The flat-plate collector has a simple construction and an easy-to-understand operation. It changes the sun's radiation into heat on a flat surface within a simple box. It can be permanently mounted on a roof or in a yard. It does not require special technology, reflecting surfaces, lens, or equipment for changing its angle in relation to the sun's position.

A typical flat-plate collector is shown in the illustration. There are seven major parts in a flat-plate collector. These are:

1. a cover plate or glazing
2. an absorber plate coating
3. an absorber plate
4. gaskets or seals
5. insulation
6. a collector box or housing
7. passages for heat-transfer medium


Gaskets/ Seals
Cover Plate (Glazing)
Risers
manifold
Heat-transfer Medium
Insulation
Absorber Plate and Coating
Housing

The glazing plate is a transparent sheet of glass or plastic that is mounted above the absorber plate. It provides an air space in the collector. The sun's rays can penetrate the glass and be transformed into heat energy on the absorber plate. The cover plate then prevents this heat energy from escaping through the front of the collector. Some designs use double or triple covers for added protection against heat loss.

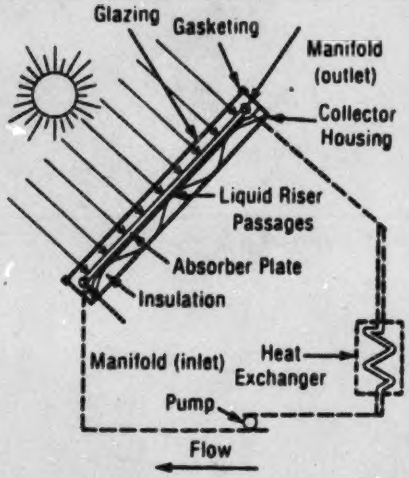
The absorber plate collects the heat energy which is transmitted through the cover plate. It has a black absorptive coating to improve its ability to absorb energy without reflecting it away. It also has passages in which the heat-transfer medium (air or fluid) can flow and carry off the heat to storage. These passages include headers and risers. The headers are main passages or manifolds through which the heat-transfer medium enters or exits the collector. They are located at the top and bottom of the collector, or on both sides. The risers are pipes that carry the heat-transfer medium across the face of the collector. They are connected to the headers, evenly spaced from one end to the other.

Insulation is packed behind the absorber plate and around the outer edges of the absorber plate. This insulation protects against heat loss through the back and sides of the collector.

All of the components of a flat-plate collector are firmly mounted in a weathertight box. This collector housing prevents moisture, dirt, dust, and air from entering the collector and affecting its performance. Rubber seals or gaskets are used to fasten the cover glazing on the housing. These seal out contaminants, but allow the cover to be easily removed if collector repairs are needed.

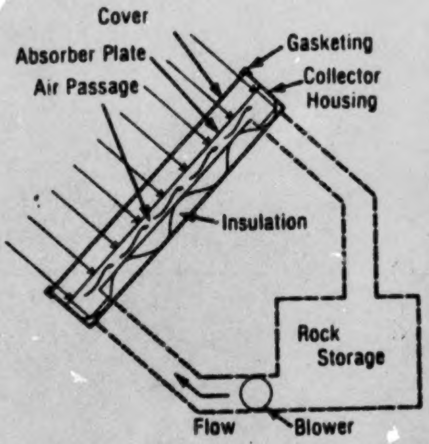
Flat-plate collectors are classified according to the type of heat-transfer medium they use. Liquid-type collectors use a liquid as the heat-transfer medium. This liquid might be water, silicone fluid, or one of several other fluids. Air-type collectors use air as the heat-transfer medium.

A cross-sectional view of a liquid-type flat-plate collector is shown in the illustration. The basic components of the collector and the collector loop are highlighted. This type of collector is used most often on solar systems that provide both water heating and space heating. Compared to air-type collectors, a liquid-type offers advantages in heat storage and heat delivery for new construction as well as existing buildings.


Glazing
Gasketing
Manifold (outlet)
Collector Housing
Liquid Riser Passages
Absorber Plate
Insulation
Manifold (inlet)
Heat Exchanger
Pump
Flow

The operation of a liquid-type flat-plate collector is very simple. Solar radiation passes through the cover glazing and strikes the absorber plate. The coating on the plate helps to absorb the radiation and turn it into usable heat. This heat, in turn, is absorbed by the heat-transfer medium in the plate's fluid passages. A pump in the collector loop circulates the heated fluid to a heat exchanger. This heat exchanger is part of a secondary pumping loop which removes the heat energy from the fluid and places it into a space-heating liquid storage tank or a water preheater tank. Then the heated fluid can be pumped away from the collector and replaced with cooler fluid.

A cross-sectional view of an air-type flat-plate collector is shown in the illustration. The basic components of the collector and the collector loop are highlighted. This type of collector is most commonly used on solar systems that provide only space heating and cooling. Its use for water heating is limited.



The operation of the air-type flat-plate collector is similar to that for the liquid-type flat-plate collector. However, air has a much lower heat capacity than water or any of the other heat-transfer liquids. About 3500 cubic feet of air are needed to transport the same amount of heat as one cubic foot of water. As a result, the air-type collector is usually much larger than a liquid-type collector of comparable capacity. The absorber plates are larger. Thin or narrow fluid passages are replaced with much thicker air ducts. The underside of the absorber-plate is usually roughened and made with fins or other such baffles to promote turbulence in the heat-transfer air. The air will not efficiently transfer heat from the absorber plate if it flows in smooth layers under the plate.

With air-type flat-plate collectors, the pump in the collector loop is replaced by a blower. And the liquid storage tank is replaced by a much larger rock-pebble storage bed. A heat exchanger is not used between the collector loop and and storage.

The design and performance of both types of flat-plate collectors is well known. Unlike other types of collectors, both collect all three types of solar radiation--direct, diffuse, and reflected. They are especially efficient at lower collection temperatures for water heating and space heating. They are not as efficient as some other collectors at the higher collection temperatures needed for space cooling.

Properly engineered and installed, the flat-plate collector is reliable, safe, and durable with known performance parameters. Designs do vary from manufacturer to manufacturer, however. The design and materials of construction can have an effect on collector performance. Later sections detail the different materials used and show you how various collector designs can be compared for efficiency. The illustration lists some of the materials usable for collector components.

COLLECTOR COMPONENT	MATERIALS USED
Cover Plate or Glazing	Glass, fiberglass laminates, thermoplastic sheeting and film
Absorber Plate Coating	Selective metal oxides, nonselective black paints
Absorber Plate	Copper, aluminum, stainless or carbon steel
Fluid Passages	Aluminum or copper tubes, integral spaces in absorber plate
Insulation	Fiberglass, glass foam, foamed thermoplastics
Housing	Metal, honeycombed concrete, fiberglass laminates, extruded thermoplastics
Gasketing	Silicone, EPDM, butyl, PVC elastomers
Heat-Transfer Medium	Air, water, silicone fluid, hydrocarbon oils water/glycol mixtures

The flat plate collector is designed to deliver energy at temperatures up to approximately 150°F ambient temperatures. Its top operating temperatures under flow conditions are in the area of 150° to 240°F. It collects direct, diffuse, and reflected radiation. It does not need to be oriented directly toward the sun at all times of the day, and it requires minimal maintenance over its lifetime. Properly designed and engineered, flat-plate collectors have a life expectancy of 20 to 25 years, perhaps longer depending on the design. The cost of energy delivered from a flat-plate collector depends on its thermal performance, its installed cost, and its effective life.

The performance of flat-plate collectors is well known and predictable. Collector efficiency is usually measured as a ratio of the useful energy collected to the incident energy striking the collector cover. As a formula:

$$\frac{\text{Energy Collected}}{\text{Energy Available}} \times 100 = \%\ \text{Collector Efficiency}$$

Major factors affecting the efficiency of a flat-plate collector are:

The rate at which heat is removed from the collector. This is labeled "F_R".

The heat losses from the collector. This is labeled "U_L".

The amount of energy transmitted through the cover and absorbed by the absorber plate. This is labeled "$\tau\alpha$".

When these factors are known, the collector performance can be predicted with accuracy. They are usually set and controlled by the design of four major collector parts:

1. The transparent covers.
2. The absorber plate coating.
3. The absorber plate design.
4. The collector insulation.

COURSE IV: INTRODUCTION TO SOLAR ENERGY

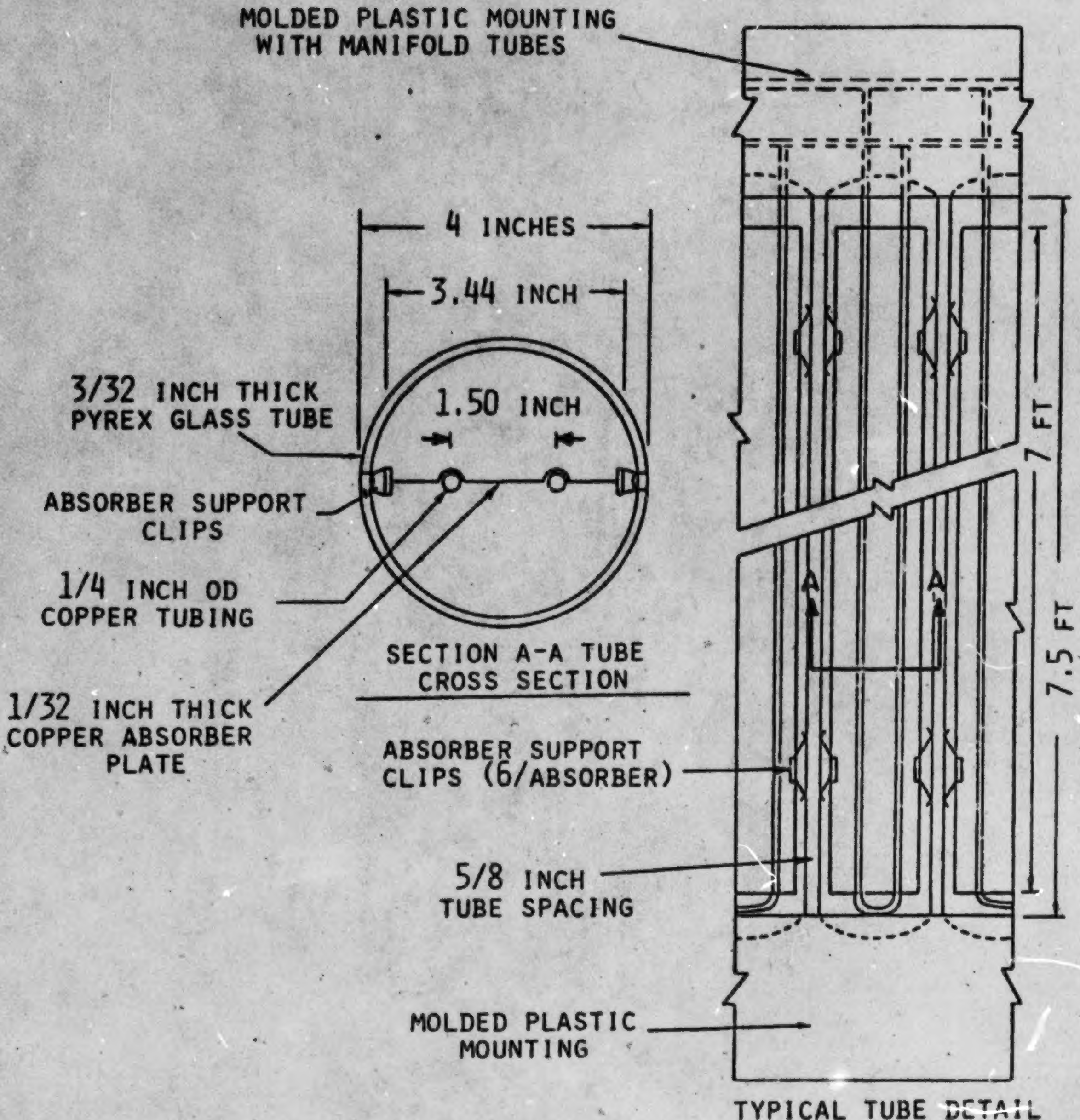
MODULE B: SOLAR ENERGY COLLECTION

UNIT II: TYPES OF SOLAR COLLECTORS

HANDOUT 2: EVACUATED-TUBE COLLECTORS

Evacuation of the air around the absorber plate is potentially a significant improvement in solar collectors. There are a number of different designs that are being assembled and tested, and at least one manufacturer makes them in moderate quantities. Evacuated collectors will produce more useful heat than standard flat-plate collectors under equal sun and weather conditions because the losses from the absorber are greatly reduced. With a vacuum surrounding the absorber, conduction and convection losses are effectively negligible and, if the absorber coating is a selective surface, the radiation loss is small.

One design, by Corning Glass Works, is shown on the following page. Inside an evacuated glass tube which is four inches in diameter is a copper absorber plate with a selective surface. Bonded to the plate is a copper U-tube which carries the heat transfer fluid. The ends of the tube protrude through one end of the glass tube, and the absorber plate is free to expand toward the other end. The efficiency

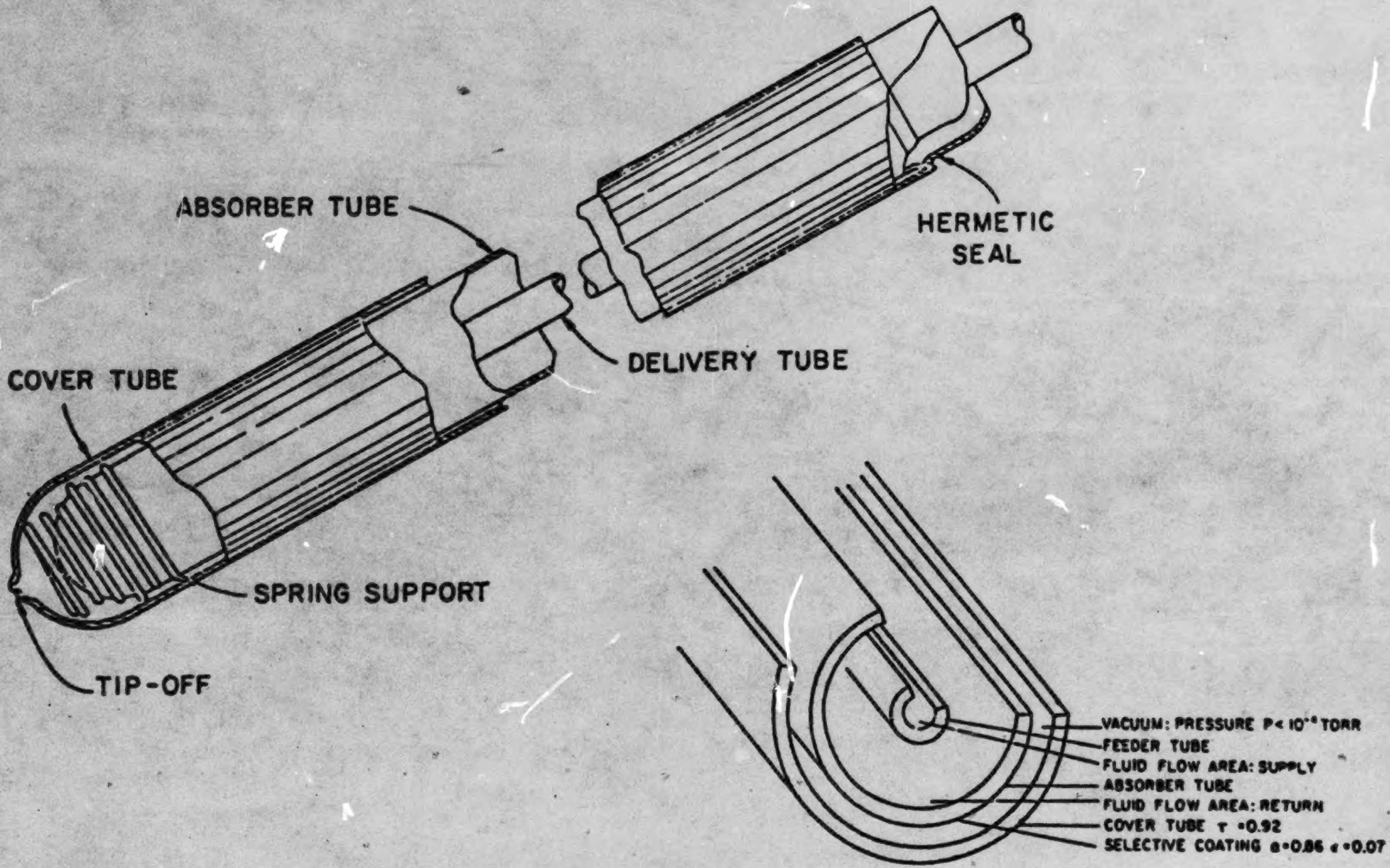

MOLDED PLASTIC MOUNTING WITH MANIFOLD TUBES
4 INCHES
3.44 INCH
3/32 INCH THICK PYREX GLASS TUBE
1.50 INCH
ABSORBER SUPPORT CLIPS
1/4 INCH OD COPPER TUBING
SECTION A-A TUBE CROSS SECTION
1/32 INCH THICK COPPER ABSORBER PLATE
ABSORBER SUPPORT CLIPS (6/ABSORBER)
5/8 INCH TUBE SPACING
MOLDED PLASTIC MOUNTING
7 FT
7.5 FT
TYPICAL TUBE DETAIL

Corning Glass Company Evacuated Tube Collector

range of the collector varies from about 74 percent when the inlet fluid temperature is low to about 60 percent when the fluid is near the boiling temperature of water. Most flat-plate collectors have high efficiency with low inlet fluid temperatures, but have low efficiencies when the fluid temperature is near boiling. The evacuated tube collector has a significant advantage when producing high temperature heat to the system and can be used effectively with solar cooling units where high temperature fluid is needed.

An evacuated tube collector design by the Owens-Illinois Glass Company is shown on the following page. There are three concentric glass tubes with the middle one coated with a black selective surface. The vacuum is between the outer and middle tubes. Fluid is transported through the inner tube and, as it passes through the annulus in contact with the absorber tube, heat is transferred from the glass to the fluid.

Two other evacuated tube collectors are being experimentally tested, one by the General Electric Company for use in air-heating systems and another is by the Philips Company in West Germany for liquid systems. Many variations in design of evacuated tube collectors are possible, and different designs will gradually advance to the practical stage.


ABSORBER TUBE
HERMETIC SEAL
DELIVERY TUBE
COVER TUBE
SPRING SUPPORT
TIP-OFF
VACUUM: PRESSURE $P < 10^{-4}$ TORR
FEEDER TUBE
FLUID FLOW AREA: SUPPLY
ABSORBER TUBE
FLUID FLOW AREA: RETURN
COVER TUBE $\tau = 0.92$
SELECTIVE COATING $\alpha = 0.86$ $\epsilon = 0.07$

Schematic of the Owens-Illinois Evacuated Tube Solar Collector

COURSE IV: INTRODUCTION TO SOLAR ENERGY

MODULE B: SOLAR ENERGY COLLECTION

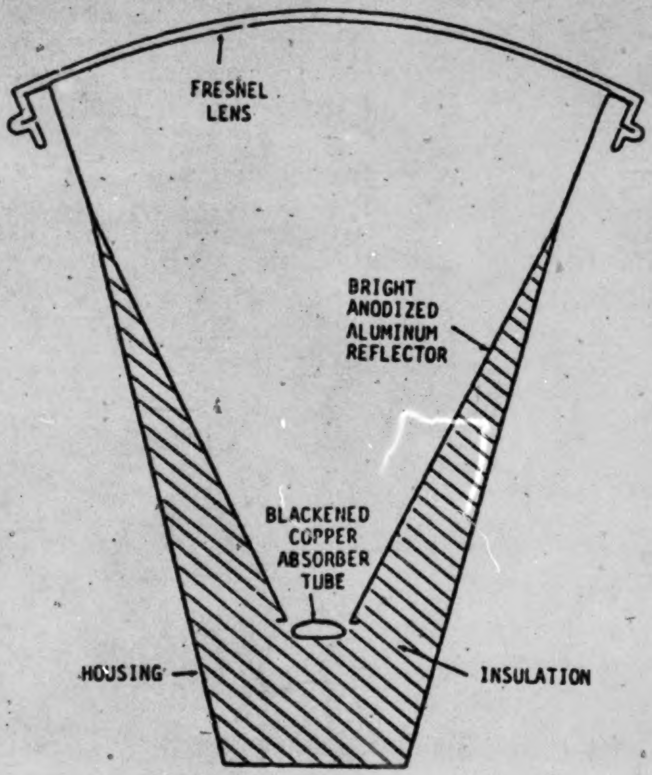
UNIT II: TYPES OF SOLAR COLLECTORS

HANDOUT 3: CONCENTRATING COLLECTORS

Concentrating collectors are sometimes called focusing collectors or tracking collectors. The sun's radiation is reflected off one or more mirrors to concentrate it onto a very small absorber area. Most concentrating collectors require mechanical devices to shift the collector position and track the sun in its travel across the sky. Some require special optical lens arrangements to help focus the sun's energy.

Concentrating collectors are used when very high temperature fluid is needed to drive heat engines or to be used in industrial processes. If concentrating collectors can be designed to be more efficient than flat-plate collectors, operate reliably, and with little maintenance so that the cost of delivering energy is low, then such collectors can have potential uses in residential solar systems. Experience thus far has indicated otherwise, but there is considerable research under way and new designs for concentrating collectors are being developed.

One type of low concentration collector is being developed by the Northrup Company and is being tested on a number of solar systems for large buildings. A linear focusing collector with a Fresnel lens is the type being developed and is shown below. The collector is mounted with the axis on the north-south direction and tilted at an angle with respect to the horizontal plane. The collector rotates from east to west during the day so that the direct rays from the sun are focused into the absorber tube. A distinct disadvantage of concentrating collectors is that only the direct rays from the sun are used, as the diffuse radiation cannot be focused.


FRESNEL LENS
BRIGHT ANODIZED ALUMINUM REFLECTOR
BLACKENED COPPER ABSORBER TUBE
HOUSING
INSULATION

Fresnel Lens Strip Solar Collector

COURSE IV: INTRODUCTION TO SOLAR ENERGY

MODULE B: SOLAR ENERGY COLLECTION

UNIT II: TYPES OF SOLAR COLLECTORS

HANDOUT 4: PHOTO-VOLTAIC CELLS

Photo-voltaic cells are special solar collectors that change the sun's energy directly into electricity. The photovoltaic cell consists of an np junction between two different semiconductors, an n-type material in which conduction is due to electrons, and a p-type material in which conduction is due to positive holes. When light is absorbed near such a junction, new mobile electrons and holes are released causing a small electrical field at the junction, resulting in electrical energy. The current produced by short-circuiting solar cells is directly proportional to light intensity and in direct sunlight is about 28 milli-amps per square centimeter. A maximum output power of about 11 milliwatts per cm^2 at an output of .45 volts. The top efficiency of these cells is around 11%.

Typical junctions for photo-voltaic cells are:

1. Silicon - silicon boride
2. Selenium - iron
3. Copper oxide - copper

Three recent reports, one commissioned by the Federal Energy Administration, and others by Congress' Office of Technology Assessment and the President's Council on Environmental Quality, suggest major and imminent reductions in the cost of manufacturing solar electric, or photo-voltaic, cells. FEA's report is especially optimistic about the impact of simple mass production technology on the costs of well-known, single crystal, electric cells.

In 1976, 300 to 350 kilowatts of solar cells were sold at the high price of $12,000 per kilowatt. For remote power production, where transmission lines are expensive to acquire and end-use needs are not great, photo-voltaics can be economic today.

An FEA report, written by the BDM Corporation of McLean, Virginia, concludes that a cost effective purchase by the Department of Defense for 153 megawatts of remotely sited solar electric cells could bring production costs down to a level competitive with nuclear power, or better, inside of six years. Obviously such conclusions have serious implications for power companies planning expansion programs, and the report has not benefitted from wide distribution.

Silicon does not need to be as pure for solar cells as is necessary for semiconductors. Therefore, the Federal Government has made available large sums of money for the

development of a less expensive solar cell. The price of solar-cell electricity has been dropping very rapidly and should become competitive in the very near future. It is now competitive in low-electrical-demand, remote areas.

COURSE IV: INTRODUCTION TO SOLAR ENERGY

MODULE C: SOLAR ENERGY STORAGE

UNIT I: INTRODUCTION

HANDOUT 1: TYPES OF STORAGE

The two principal types of storage, water storage and rock bed storage, are in common use today. Both types are based on sensible heat storage, in which the quantity of heat stored is directly proportional to the temperature rise in the storage medium. Storage of heat in water is normally used with a hydronic system and storage in a rock bed is normally used with a hot air system. Water has a high capacity for heat storage and, although rocks have one-fifth as much as water, both rocks and water are inexpensive.

Another heat storage possibility is the use of phase change materials like eutectic salts. These materials store latent as well as sensible heat. That is, they utilize the heat of liquefaction as the primary means of storing heat. Large amounts of heat can be stored and released by the process of melting and solidifying without change in temperature. One advantage in the use of these materials is that smaller storage size is needed as compared with a water tank or a rock bed. However, there are a number of problems that are associated with these materials that have been examined by researchers for years and have not as yet been resolved. Heat may be stored for use in heating and cooling residential buildings in the forms of latent heat, sensible heat, and the combination of latent and sensible heats.

Latent heat can be stored by melting a solid, such as wax, into a liquid. The stored heat is released when the temperature drops and the heat which is released is supplied to the conditioned space. If a suitable material is used, solar heat at temperatures provided by collectors can be used to melt a solid and to store the heat during the day, then be made to release the heat when the liquid changes back to a solid form. Only a small temperature difference is enough to alter the phase from solid to liquid or liquid to solid. The use of ice to cool an "ice box" and to cool liquids is an example of the use of latent heat for cooling.

There are also two principal advantages to latent heat storage. As very large quantities of heat can be stored and released per pound of material, it takes much less volume to store the heat required by the system. A latent heat storage unit using wax would require about one-fourth as much volume as a water tank to store an equivalent amount of heat. A second advantage is that the temperature remains nearly constant during phase changes. A steady operating temperature for hot storage or cold storage is particularly advantageous for operating a chiller.

However, there are some disadvantages with latent heat storage units. Many known latent heat materials will last only a few years then must be replaced. Suitable materials are costly when compared to water or pebble-bed storage units. More time is needed for development of practical latent heat storage units.

Sensible heat is stored when the temperature of a storage medium increases. Water and pebbles are the common materials used for sensible heat storage because they are low in cost and readily available. Any thermally and chemically stable solid or liquid may be used if the costs are justifiable.

The amount of heat required to raise the temperature of one pound of matter one degree is the heat capacity of the material. Water has three times the heat capacity as compared to rock for the same volume. This means that a pebble-bed storage unit would be three times larger than a water tank to store the same amount of heat.

COURSE IV: INTRODUCTION TO SOLAR ENERGY

MODULE C: SOLAR ENERGY STORAGE

UNIT I: INTRODUCTION

HANDOUT 2: STORAGE LOCATION, SIZE AND HEAT LOSS

LOCATION

Solar heat storage units may be located above or below grade and either inside the heated building or outside. It is advised that the storage unit be placed within the building enclosure whenever possible and close to other solar equipment. An inside storage location has the advantage in that it is protected from moisture and cold, and the heat loss from the storage unit will aid in heating the building in winter. The disadvantages of locating the heat storage unit inside are that heat loss to the building adds to the cooling load during the summer and a finite amount of relatively expensive space must be provided.

When a storage unit is placed underground, the insulation must be of a material which will not absorb moisture. Neoprene foam or styrofoam could be suitable. The tank should be placed below the frost line unless a concrete lined pit is provided for the tank, pumps, and other equipment. The pumps, which circulate the storage water, should be placed at a level to prevent vapor locking at the impellers.

STORAGE SPACE

Precise heat storage sizing is not required for solar systems, but there is an economical size for a given installation. A very large volume of storage does not result in providing more solar heat to the building enclosure as compared to an adequately sized unit. Thus, a disproportionately large storage capacity relative to a fixed collector area is not useful.

A solar system that is to provide a major fraction of the annual heating load for a building should provide for overnight heating from the solar energy collected during an average winter day. If the previous day was cloudy, then the system will depend upon the back-up unit to provide heating. A large solar collector area which provides more heat than is needed by the building will have excess heat that can be stored in a large storage volume. Such a system could store enough heat for use over several days if there is no sunshine. The cost of the system increases, however, because of the larger collector area and storage volume. The most practical size to consider is a solar system that will provide for 20 to 30 hours of heating during average winter days. The recommended size of storage relative to collector area is one to two gallons of water for a liquid system, or one-half to one cubic foot of pebbles per square foot of collector area for an air system. A solar system for a residence with 500 square feet of collectors should have a storage unit with about 700 gallons of water capacity, or 300 cubic feet of pebbles. The installed cost of such a storage unit would range from $500 to $1,000.

STORAGE HEAT LOSS

If the heat storage unit is installed inside the building enclosure, the heat loss from the unit will be to the building interior. In the heating season the heat is effectively utilized, but in the summer the heat loss from storage will add to the cooling load. By placing the storage unit within a vented and insulated room, use of the heat loss from storage can be effectively controlled during winter and summer.

COURSE IV: INTRODUCTION TO SOLAR ENERGY

MODULE C: SOLAR ENERGY STORAGE

UNIT II: WATER AND ROCK STORAGE

HANDOUT 1: INTRODUCTION TO WATER STORAGE

Water should be used for heat storage if a liquid is used as the heat transport medium in the solar collectors. If an antifreeze solution is needed in the collectors, separate the fluid circulation loops with a heat exchanger between the collector and storage loops. If freezing is not of concern, water from storage may be circulated through the collectors without a heat exchanger and the storage water is pumped directly to the heating coils or the absorption cooling unit.

Four conditions must be avoided when using water for heat storage:

1. Freezing
2. Boiling and pressure build-up
3. Corrosion
4. Leakage

Because it is prohibitively expensive to provide ample antifreeze in a water storage tank to protect from freezing, it is recommended that the water storage tank be located inside the building or underground below the frost line. A storage tank inside the building is more desirable than one underground. Heat loss from underground tanks is not recoverable for useful purposes. Also, indoor tanks are more accessible for repairs.

Boiling and pressure build-up can occur in the storage tank and provisions should be made to prevent damage to the system or to the contents of the building. While it is an uncommon occurrence for well-designed systems during the heating season, frequent boiling may be expected during the summer if the heat is not used to operate a chiller. The steam can be vented outside the building to prevent pressure build-up in the tank and to release the heat from the system. A pipe from the top of the tank to the outdoors with a low pressure relief valve is sufficient. A float-controlled valve to provide make-up water in the storage tank should be provided. Boiling of storage water will cause build-up of mineral deposits with consequences in corrosion unless water softeners are used.

A high temperature shut-off control on the collector pump may be used with some collectors to avoid boiling. Many collectors, however, are not designed to withstand the high temperatures which result from no flow for an extended period; thus, the practice of stopping circulation is dependent upon the type of collector that is selected.

Corrosion is a potential problem whenever water is contained in a metal tank and the probability of corrosion greatly increases with temperature. Fiberglass lining to protect against corrosion and water softeners will increase the life of the tank but will be an added expense.

Corrosion usually occurs at the pipe connections to the tank. If dissimilar metals are used, galvanic corrosion will result. Therefore, neoprene rubber hoses should be used to connect copper pipes to steel tank fittings.

Water leakage must be prevented because it can damage tank insulation and other materials near the tank. Because there is difficulty in locating a leak after insulation is applied, the tank should be leak-tested with all fittings in place before insulation is applied.

COURSE IV: INTRODUCTION TO SOLAR ENERGY

MODULE C: SOLAR ENERGY STORAGE

UNIT II: WATER AND ROCK STORAGE

HANDOUT 2: INTRODUCTION TO ROCK STORAGE

Heat is stored in a rock bed by circulating heated air from the collectors directly through the rock bed. In contrast to the water storage tank, the rock bed is not heated uniformly, but is heated gradually to the temperature of the air stream coming from the collector. This results in temperature stratification, where the top of a rock bed is at the collector air temperature and the bottom of the rock bed is at room temperature. The advantages in stratification are that cold air is returned to the collector so that the collector operates more efficiently. Also, the air temperature is high for heating from storage at night.

Solar heated air is passed directly through the rock bed from top to bottom. As the air passes through the pebbles, heat is transferred from the air to the rocks so that the rock temperature rises. The cool air which leaves the bottom of the rock bed is returned to the collectors to be reheated. The top of the rock bed will be warmer than the bottom because of hot air supply from the collectors. After sundown and the discontinuance of air circulation, the rock bed will maintain this temperature stratification because heat conduction through the bed from one pebble to another is small.

The stored heat is delivered to the building by circulating room air through the rock bed in the direction opposite that of the storing cycle, that is, from the bottom toward the top of the rock bed. As the cool air flows through the spaces between the pebbles, it is heated and the warm air is recirculated to the rooms. The bottom of the rock bed is always at the lowest temperature, usually room temperature, and because the coldest air is delivered to the collectors, the collectors operate at maximum efficiency.

The hot end, or collector supply end, of the rock bed is preferably at the top to prevent heat loss to the floor. If the layout requires the hot end at the bottom, two inches of rigid fiberglass board should be placed under the unit to reduce heat loss to the floor.

COURSE IV: INTRODUCTION TO SOLAR ENERGY

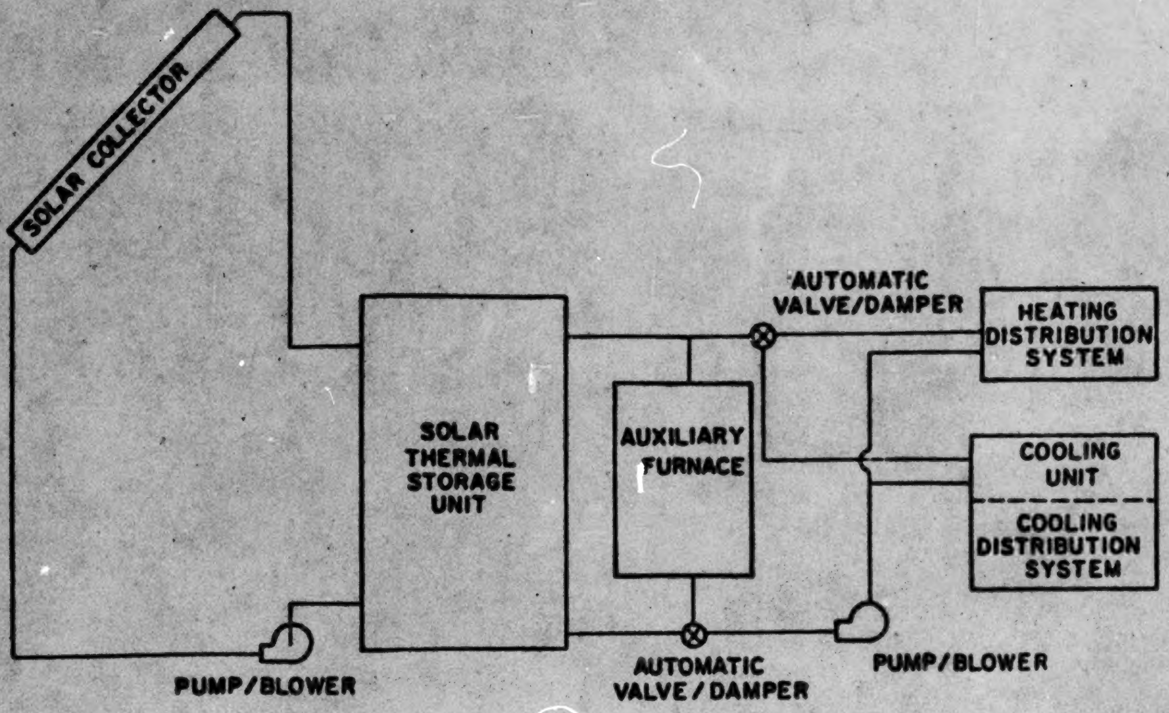
MODULE D: SOLAR SYSTEMS

UNIT I: INTRODUCTION TO SOLAR SYSTEMS

HANDOUT 1: ACTIVE SYSTEMS

Any system which utilizes solar energy to heat and/or cool a building can be defined as a solar heating and/or cooling system, however a distinction is often made between "passive" and "active" systems. A passive system can be defined as having no moving parts, although it may involve natural circulation of fluid to the heated space. A south-facing window or skylight which transmits sunlight can be considered a passive system if it admits more energy than it loses as heat. Another type of passive system may involve movable insulation material which reduces heat loss from solar absorber surfaces when there is no sunshine. In contrast to a passive system, an active system involves hardware to collect solar energy, store heat, and distribute the heat to the rooms in a building.

The emphasis in this course is on active solar systems which provide controlled collection and distribution of solar heat. Active systems can be integrated directly into conventional HVAC systems in buildings.


SOLAR COLLECTOR
SOLAR THERMAL STORAGE UNIT
AUXILIARY FURNACE
AUTOMATIC VALVE/DAMPER
HEATING DISTRIBUTION SYSTEM
COOLING UNIT
COOLING DISTRIBUTION SYSTEM
PUMP/BLOWER
AUTOMATIC VALVE/DAMPER
PUMP/BLOWER

Schematic Drawing of a Solar Heating and Cooling System

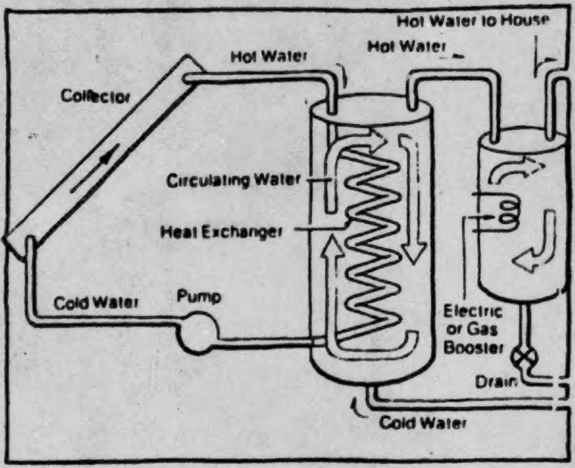
The above schematic drawing of an active solar heating and cooling system is a representative of those available today. The key elements are a solar collector, a heat storage unit, an auxiliary furnace, a heat-transfer circuit (pumps, blowers, etc.), a method of delivering heat to the house, and a cooling machine for space cooling. Plus, many solar systems include facilities for providing solar heat to the domestic hot water system.

Operationally, the solar collector intercepts solar radiation, converts it to heat and, utilizing some heat-transfer fluid, transfers the collected energy to a thermal storage unit (or, in some cases, directly to the heating load). The thermal storage unit is an essential element because it provides for the use of solar generated heat to be available during periods of low solar radiation and at night. In general, the solar collector and thermal storage unit can operate independently of any heating or cooling requirement, and can be collecting and storing solar energy whenever there is sufficient incident solar radiation.

An auxiliary furnace is required as a back up to the heating/cooling system for periods of the year when the solar collector/thermal storage subsystem is unable to meet the heating/cooling demands. While the solar collector could be sized large enough to provide the full heating load throughout the year, this is not as economical as an auxiliary assisted system. It is preferable to have an auxiliary furnace or boiler capable of meeting the full heating/cooling demand (at design conditions) and use this auxiliary during periods of high heating/cooling demands and low solar availability.

There are several ways to accomplish heat delivery to the building. In an air system the solar heated air can be taken directly from either the solar collector or the thermal storage unit and delivered to the building by utilizing a blower and duct distribution. In a liquid system a liquid-to-air heat exchanger can be used to provide heat to a central air distribution system, or the liquid can be piped directly to the heated space, where separate fan coil units can be used to heat the building.

A number of different methods can be used for cooling. These include absorption cooling units (both lithium-bromide and ammonia-water systems), Rankine cycle vapor-compression, and others. (However, only the lithium-bromide absorption unit is commercially available and it has been used only in experimental installations.) Alternatively, a heat pump might be utilized as a conventional cooling unit (powered by electricity) and used as the auxiliary for the solar space heating system.


Hot Water to House
Hot Water
Hot Water
Collector
Circulating Water
Heat Exchanger
Cold Water
Pump
Electric or Gas Booster
Drain
Cold Water

A typical schematic drawing (at right) shows the arrangement of components for utilizing solar heat in a domestic hot water system (DHW). Solar energy from a collector or a thermal storage unit is used to preheat the domestic hot water available from the cold water main. As hot water is used in the building, the preheated water replaces the hot water taken out of the auxiliary hot water tank. Conventional fuels such as gas or electricity are used to boost the temperature of the preheated water to the desired temperature (e.g., 140°F), and/or to maintain the temperature of the water remaining in the auxiliary tank at the desired temperature. During the summer a solar thermal storage unit provided.as part of the heating and cooling system can normally meet one hundred percent of the domestic hot water load.

In addition to the components of conventional heating and/or cooling systems normally required to meet the heating and cooling loads, a solar system requires the addition of solar collectors, thermal storage units, DHW preheat tanks, some additional plumbing/sheet metal work, and more extensive control systems. The emphasis of this course will be to provide the details of these additions to the conventional systems and the interfaces between the solar subsystem and the conventional HVAC components. Of the additional solar components, the most important is the solar collector.

COURSE IV: INTRODUCTION TO SOLAR ENERGY

MODULE D: SOLAR SYSTEMS

UNIT I: INTRODUCTION TO SOLAR SYSTEMS

HANDOUT 2: BUILDING DESIGN AND THE PASSIVE SYSTEM

Building design should go beyond the standard energy-conserving construction used by good builders of today. Our energy dilemma calls for additional energy conservation by incorporating passive design ideas, and by using solar energy through passive systems, in its planning, design, construction and use. Building location, siting, orientation, configuration, layout, construction, mechanical and electrical systems, casework, and interior furnishings are all carefully evaluated in terms of their contribution to energy consumption and conservation. Natural energies are used to their fullest.

Some design priorities follow:

1. Make every effort in planning, design and construction to minimize heat loss in the winter and heat gain in the summer.
2. With this objective achieved, put forth every effort to incorporate into houses passive design characteristics which use natural energies such as solar radiation, natural lighting and prevailing winds.
3. Where possible, economical and efficient, incorporate

active technologies which use renewable energies into designs.

4. Then, and only then, should we rely on fossil-based or non-renewable energies (and related equipment and design features) to supply the remaining energy required.

Passive design concepts that require no change in life style might include:

1. One-story building configuration
2. Earth berming to the window sills
3. Reflective surfaces within the envelope
4. Flexible walls
5. Atrium/greenhouse
6. Individual hot water system
7. Entry locks
8. Closets located against exterior walls
9. Individual heating zones with clock thermostats
10. Window sash and insulated glass
11. Window shutters

Management ideas might include:

1. Temperature during heating season maintained at 70°F during occupied times and 55°F at all other times is a management priority.

2. House includes operable shutters (U value: .115) which are open from 8 a.m. to 4 p.m. in the wintertime. Summer schedule for shutters on east windows is 1 p.m. to 4 p.m.; shutters on south windows, 7 a.m. to 9 a.m. and 3 p.m. to 5 p.m.; west windows, 8 a.m. to 11 a.m.; and north windows, 8 a.m. to 7 p.m.

ORIENTATION FOR SOLAR GAIN AND FOR NATURAL VENTILATION

Some compromising will be necessary because solar gain and natural ventilation cannot always be maximized by the same orientation.

1. For passive solar collection, south-facing glass should total 1/4 to 1/5 of the floor area (temperate climates) or 1/3 to 1/4 of the floor area (colder climates). These are general rules which, in temperate climates, and with appropriate insulated shutter and heat storage mass, can provide between 40% and 90% of the heating required.
2. Use an isogonic chart to locate 'south'. (Remember, a compass indicates magnetic, not true, north.) Additional data on solar altitude and bearing for your area, and for critical times of the year, are available from the Weather Bureau or Solar Atlases.

3. Be sure that trees, hills and/or buildings do not cast shadows on your south-facing glass during the winter. (Also insure that your building does not infringe on the 'solar rights' of others.)
4. Design overhangs to provide full shading of glass areas in the summer and during the most intense solar insolation periods. Deciduous trees on the south side will also help--providing shading in the summer and permitting solar penetration in the winter.
5. In orienting the building, remember that each facade has its own climatic conditions and thus its own energy conscious design characteristics. As an example, vertical shutters may be appropriate on one facade, horizontal on another and sliding on a third.
6. Locate the facade through which breezes will enter at an angle of 20° to 70° between wall and wind direction. This increases turbulance and provides better ventilation.
7. When wind velocity is low, it is beneficial to maximize the velocity of the ventilating currents. This can be done by using wing-walls extending from the exterior wall to create mini-pressure zones in front of the window openings. The depth of the projection should be no more than one-half of the distance between windows on the same facade. Casement windows,

or operable shutters, extended perpendicularly to the wall can serve the same function.

8. Window sills should be located at the height where ventilation is desired. In bedrooms, for example, sills should be located at the same elevation as the mattresses inside.
9. Locate evergreens on the north and west sides to block arctic winds.
10. When sites slope, particularly to the south, breezes move up the hill by day and down at night. Near bodies of water, breezes move from water to land by day and from land to water at night.

Some general rules to keep in mind while designing a passive solar collector:

1. Locate a maximum amount of living space so that it has a southern exposure.
2. Use true north--not magnetic north--in locating the south elevation.
3. The amount of south-facing glass area depends on the amount of passive heating desired and the insulation characteristics of the site. As general guidelines, include 1/4 to 1/5 of the floor area to be heated as south facing glass in temperate climates. In colder

climates, increase the ratios to 1/3 to 1/4 of the floor area.

4. To store heat, sufficient water, masonry and other storage media are required. In temperate climates, and where surfaces will have direct exposure to the sun, provide 30 pounds of water or 150 pounds of masonry for each square foot of south-facing glass. Where exposure to the sun is indirect, the mass of the material will have to be increased (by a factor of four).
5. For storing the heat energy, think of all fixed elements in the structure (walls, floors, ceilings, furniture, flower beds, etc.) as heat storage masses. The ratio of building floor area to storage mass surface area should be at least 1:1.
6. Masonry or concrete wall thickness of more than 8" has little effect on daily thermal storage. Thicker walls, however, will help store heat for cloudy days.
7. The surfaces of thermal masses should be dark where possible. Use light colors on floors to prevent excess surface temperatures.
8. Insulating shutters are essential components of passive solar systems. Use them on the exterior to keep heat in at night, and on the inside to keep heat

from radiating into the room when it is not desired.

9. Shade glass walls to reduce heat gain when it is not wanted. To do this, determine the sun's altitude at noon during the hottest summer month, and design your shade or roof overhang to put the entire wall in shade. For winter conditions, find the sun's altitude at noon in the coldest month; your overhang should leave the full wall in as much sun as possible.

Ideas to keep in mind before building underground:

1. Gentle south slopes are ideal for underground structures. You can easily build into the hill, have south sunlight and positive drainage.
2. Avoid low-lying depressions. Heavy cold air drains into them; frost and dampness are more likely in these areas.
3. Make sure that surrounding construction (parking lots, septic systems, etc.) do not drain into the site.
4. Identify ground water levels (including seasonal variations) before making decisions on placement and depth.
5. Adequate soil percolation is essential, particularly for sunken courtyards and atriums. If there are problems, consider the installation of overflow drains.
6. Any structural system can be used, provided it is designed to applicable loading conditions. General

rules are 150 PSF for roofs with grass cover, and 400 PSF for roofs when the earth cover is to support small trees. Add snow, water and pedestrian loads.

7. Wall design is generally the same as conventional basement wall or other below-grade construction.
8. Place insulation on the outside of the below-ground building structure; this allows the structure to serve as a heat-storage mass. Insulation can be reduced in thickness as the depth below grade increases. The best current insulating material for this application is styrofoam with its closed cell construction.
9. Butyl sheets provide both waterproofing and a vapor barrier.
10. For earth berming against existing exterior walls, a cement plaster finish applied to metal lath and a vapor barrier on the existing wall will do the job. This detail also discourages roots, insects and rodents from getting into the wall.
11. Avoid curbs or parapets to retain earth roof covering. Freezing and thawing action will tend to crack these elements.
12. To control interior dampness, dry the air through circulation and/or dehumidification.

13. Earth pipes can be used to provide natural cooling. Air taken from the outside during warm weather can be cooled by passing it through long pipes buried in the berm or below grade. The same piping can provide some degree of preheating fresh outside air during cold weather.
14. Examine local codes, especially in relation to fire exits and ventilation.
15. Lighting usage should be thought out carefully. It will affect both comfort and energy use more critically in an underground house.

Underground structures are now the subject of a great deal of research. Before embarking on such an undertaking, a review of the latest research results is highly recommended.

Greenhouses attached to residences can perform two key passive design roles:

1. as secondary skins, effectively raising the temperature just outside the building's exterior wall in the winter (and, if plants and shading devices are used, lowering it in the summer) and
2. as passive solar collectors.

For passive design purposes, these simple rules-of-thumb may be of value:

1. A greenhouse can be constructed as a secondary skin on any facade--but a south-facing greenhouse makes the best passive solar collector.
2. The wall between the greenhouse and the residence must be insulated to control heat flow and to prevent overheating.
3. Wall surfaces directly exposed to the sun should be dark-colored. Floors should be light-colored if there is danger of them becoming too warm.
4. Insulated shutters allow the greenhouse to retain the heat collected after the sun has gone down.
5. The distance from the exterior wall of the greenhouse to another object on the landscape (a tree, another building, etc.) should be at least 2½ times the height of the wall.

Building an attached solar greenhouse is rapidly becoming popular as a source of energy, of fresh food and/or of flowers right through the winter. A traditional greenhouse usually was constructed without much regard for the most effective use of the sun's energy. A solar greenhouse, if constructed properly, will collect solar energy efficiently, store solar energy, reduce heat loss and provide light zoning for various plants.

COURSE IV: INTRODUCTION TO SOLAR ENERGY

MODULE E: FUTURE OUTLOOK FOR SOLAR

UNIT I: BARRIERS AND INCENTIVES

HANDOUT 1: BARRIERS

There are several significant barriers to widespread application of solar energy systems in homes, and there are a few incentives that could be created to induce greater use. The greatest barrier to solar system utilization is the lack of understanding of solar heating and cooling systems among homeowners, contractors, engineers, architects, and others in the home building industry. This course is intended to overcome some of the lack in knowledge about solar systems. The initial cost of systems is another barrier, but understanding the economics of solar systems, and the rising cost for fuel, will assist in overcoming this barrier. Among the greatest incentives for homeowners to install solar systems is to provide substantial credit against the initial cost. The credits can be for income and property taxes. These and other barriers and incentives are discussed in this unit.

EDUCATION

Unless the homeowner is a technically oriented person, the potential customer for a solar heating system is likely to have minute basic understanding of a solar heating and cooling system. The building contractor, or HVAC installer, is given the responsibility of explaining the system, the components, and the performance of systems as compared to standard heating and cooling methods. The knowledge gained from this course can be used effectively by the trainees to explain the kinds of solar systems available and the probable performance of the systems in residential buildings.

The contractor should emphasize the economic aspects of solar heating and cooling systems--how, despite high initial cost, the cumulative costs after approximately 10 years will favor the solar system. It should be explained that a solar system can provide the major fraction of the annual heat load, and an auxiliary unit is required, but the energy consumption and costs are substantially decreased.

INSTITUTIONAL CONSTRAINTS

Solar heating and cooling systems are new to the legal, financial, and insurance institutions and face existing and, perhaps, new institutional constraints. Fortunately, there are few barriers established to constrain installation of solar systems, but characteristically laws are written after problems occur, financial policies are developed after experience is gained, and insurance rates are based on risk factors and probabilities.

LEGAL

Access to Sunlight

An important aspect of solar systems is full access to sunlight. While zoning can be effective, it is not a guarantee to continued access to sunlight because zoning can change. A high-rise building on the south side of a residence with a solar system can be devastating. Though total shading by other structures is avoided, shadows cast by the neighbors' tall trees can be a serious problem. At present, the owner of an adjacent lot can plant any tree he wishes--except if the height may interfere with utility lines. The concept of a solar easement has some merit, but has not been enacted anywhere at this time.

Land Use and Zoning

Land use legislation and zoning restrictions can restrict the usefulness of solar energy systems by regulating the placement of collectors. On the other hand, regulations can also encourage the use of solar systems by requiring street layouts to maximize solar energy use. Restrictive regulations regarding architectural style or materials of construction should be scrutinized. It is difficult, for instance, to build a solar house in a subdivision that permits only shake shingle roofs. Likewise, a restriction on the orientation of a building on the lot could hamper the collector orientation.

Building Codes

There are virtually no building codes in the United States which deal specifically with solar heating systems or components thereof. Some efforts toward establishment of specific codes have been started, but until criteria and standards have been set by national agencies, the information on which local authorities must base their codes for solar equipment is not available.

Most building codes, however, have provisions which can be applied to solar heating equipment as part of the structural and heating components of a building. Requirements as to roof load capability, structural integrity, flammability of material, ventilation requirements, and so on, have restrictive as well as proscriptive influence on solar equipment. Therefore, it is necessary for an installer and owner of a solar heating system to comply with such terms in the local codes. The manufacturer, in turn, will be required to conform if his hardware is to be sold and used in a particular area. For example, if a local code requires Underwriters Laboratory certification on heating units in a building, then the manufacturer and installer would be required to use only such equipment in the solar system.

Up to now, building inspectors appear to have encountered no serious problems in approving solar heating installations. With probably over a thousand solar heating systems in the United States, it is evident that the lack of specific codes on solar heating equipment has not significantly deterred its use.

Since a full-capacity conventional heat supply is required in almost all areas where building codes apply, there is no appreciable danger that a solar heating system would fail to keep a building at a comfortable and safe temperature. Even if the efficiency of a solar heating system is far less than expected, a code authority could still approve such a system without transgressing code requirements.

Generally, an owner or contractor planning to install a solar heating system should contact the local building inspector prior to the expenditure of major effort on the project in order that any questions which may relate to compliance with the code could be resolved in advance. If a particular solar heating system or component clearly violated a code requirement, a change to some other type of hardware could be made prior to expenditure of significant funds on a system which would not be acceptable.

FINANCIAL

Financing is available for solar systems from a few lending institutions. Because information about system performance, reliability, and life times is meager, many savings and loan companies do not have established policies. Some loan money for the entire building project, less the down payment, purely on the ability to pay the mortgage. Others restrict loans to projects that include approved solar systems, and still others loan money only on the basis of the type of auxiliary unit that is used in the solar system. If loan companies provide financing only for the building, and not for the solar system, there is a financial barrier to installing solar systems.

INSURANCE

Insurance companies have shown no reluctance to insure solar houses at rates comparable to other houses. There has not been sufficient experience to change the insurance rates for solar houses from non-solar homes.

COURSE IV: INTRODUCTION TO SOLAR ENERGY

MODULE E: FUTURE OUTLOOK FOR SOLAR

UNIT I: BARRIERS AND INCENTIVES

HANDOUT 2: INCENTIVES

The greatest incentive for solar heating systems is the rising energy cost and the lack of alternatives to electricity for heating. Other incentives are being created in the form of tax relief. For example, several states have reduced or eliminated the property tax assessment on new solar systems and a few states have provided deductions on state income tax returns for owners of solar heating systems in their homes. The Federal Income Tax Relief is added to the state deductions.

In addition to fundamental security, solar and renewable sources of energy provide numerous social and environmental benefits.

Energy from the sun is clean and safe. It will not pollute the air we breathe or the water we drink. It does not run the risk of an accident which may threaten the health or life of our citizens. There are no toxic wastes to cause disposal problems.

Increased use of solar and renewable sources of energy is an important hedge against inflation in the long run. Unlike the costs of depletable resources, which rise exponentially as reserves are consumed, the cost of power from the sun will go down as we develop better and cheaper ways of applying it to everyday needs. For everyone in our society--especially our low-income or fixed-income families--solar energy provides an important way to avoid rising fuel costs.

No foreign cartel can set the price of sun power; no one can embargo it. Every solar collector in this country, every investment in using wind or biomass energy, every advance in making electricity directly from the sun decreases our reliance on uncertain sources of imported oil, bolsters our international trade position, and enhances the security of our Nation.

Solar energy can put hundreds of thousands of Americans to work. Because solar applications tend to be dispersed and decentralized, jobs created will be spread fairly evenly around the Nation. Job potentials span the ranges of our employment spectrum, from relatively unskilled labor to advanced engineers, from plumbers and metal workers to architects and contractors, from scientists and inventors to factory workers, from the small businessman to the large industrialist. Every investment in solar and renewable energy systems keeps American dollars working for us here at home, creating new jobs and opportunities, rather than sending precious funds to a foreign cartel.

Increased reliance on solar and renewable technologies can also increase the amount of control each one of us as individuals and each of our local communities has over our energy supplies. Instead of relying on large, centralized energy installations, many solar and renewable technologies are smaller and manageable by the homeowner, the farmer, or the individual factory or plant. By their very nature, renewable technologies are less likely to engage the kind of tension and conflict we have seen in other energy areas, such as the problems posed by siting a very large energy facility, or trading off between surface uses of land and development of the energy minerals that might lie below that land.

Finally, solar and renewable technologies provide great international opportunities, both in foreign trade, and in the ability to work with developing nations to permit them to harness their own, indigenous resources rather than become dependent on fuels imported from other nations.

It is a mistake to think of solar energy as exotic or unconventional. Much of the technology for applying the sun's power to everyday tasks has been in use for hundreds of years. There were windmills on our great plains long before there were high tension wires. There were factories in New England using waterpower long before the internal combustion engine was invented. In Florida, before World War II, there were more than 60,000 homes and buildings using solar hot water heaters. The Native Americans who built the great cliff dwellings of the West understood and applied solar heating principles that we have neglected in recent years, but which are available for us to use today.

These traditional and benign sources of energy fell into disuse because of a brief glut of cheap crude oil. These years are over. That inescapable fact is not a cause for despondency or a threat to our standard of living. On the contrary, it presents us with an opportunity to improve the quality of our lives, add dynamism to our economy and clean up our environment. We can meet this challenge by applying the time-tested technologies of solar power, and by developing and deploying new devices to harness the rays of the sun.

COURSE IV: INTRODUCTION TO SOLAR ENERGY

MODULE E: FUTURE OUTLOOK FOR SOLAR

UNIT II: SOLAR ECONOMICS

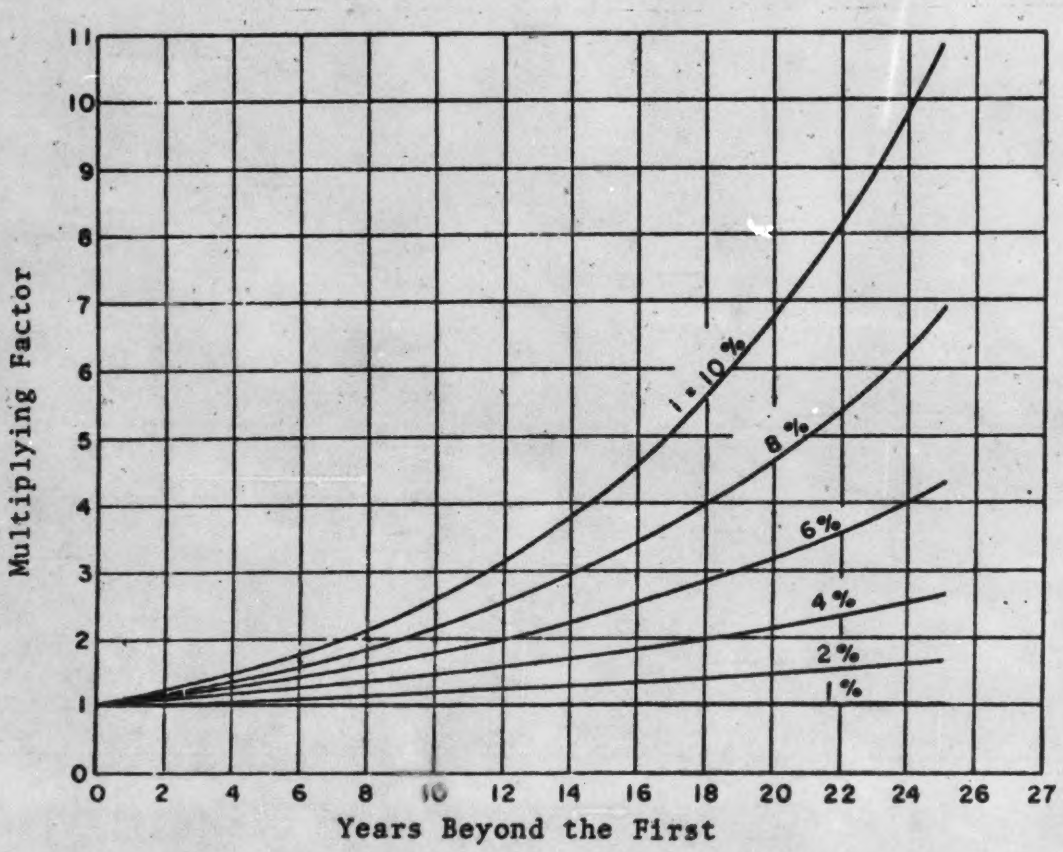
HANDOUT 1: SOLAR COSTS

The main portion of the cost of heating a house with a conventional heating system is the cost of energy used by the system. A significant portion of the cost of heating a house with a solar system includes payment for solar hardware as well as energy used by the auxiliary unit in the solar system. While the capital investment in a conventional heating system is usually less than $2,000, the capital investment in a solar heating system is several times that amount.

An economic analysis of solar systems involves comparison of the capital and operating costs of a solar system with the operating costs of a conventional system. Among the many methods available, the method of life-cycle cost is explained in this unit. In this method, the annual cash flows for solar and non-solar systems are considered. If the cumulative difference in cash flows (non-solar minus solar) is positive over the life of the solar system, then the solar system is economically viable.

The cost of energy will increase in future years and an estimate of the rate of increase is subject not only to inflation rates of goods and services, but also to economic and political decisions of the federal government and the governments of other nations. One expects, therefore, the rate of fuel cost increases to be different from "normal" inflation rates.

The increases in costs per unit of energy, several years in the future, in terms of cents per gallon, cents per kilowatt-hour, cents per hundred cubic feet of natural gas, or dollars per therm, can be estimated on the basis of annual percentage increases over current costs. The multiplying factors for current energy costs to determine future costs are:



The horizontal axis is the years beyond the current year. The vertical axis gives the multiplying factor over current costs. For example, if the current cost of electricity is expected to increase at a rate of 6 percent each year for the next 12 years, at the end of 12 years the electricity cost will double. If 5 cents per kilowatt-hour is the current cost and heating cost is 14.67 per million BTU, at the end of 12 years the electricity will cost 10 cents per kilowatt-hour and $29.33 per million BTU.

SOLAR SYSTEM COSTS

There is much speculation about the installed costs of complete solar systems and there is little information available to substantiate published information on costs. System costs based on research projects and demonstration projects funded by the federal government are misleading because the total costs of such projects include considerable engineering design costs, research staff costs, in some instances instrument costs for monitoring the performance of experimental systems; and often development costs of several alternative components in the systems are included. The costs reported in popular magazines and newspaper accounts are likewise misleading because often systems which are designed and assembled by the owner on a do-it-yourself basis are cited and cost for the owner's time is seldom included in the cost quotations.

On the basis of a few commercial solar installations made, where no governmental subsidy has been involved, the installed costs of practical solar space and hot water heating systems of the types discussed in this course range from 19 to about 30 dollars per square foot. The lower cost is appropriate for simple hydronic and air systems, ranging in size from 500 to 1000 square feet of collectors, where some economy of scale is realized over small systems and where experienced installers and timely scheduling are arranged with the building construction. The higher costs are appropriate for smaller systems and difficult installations.

The costs for collectors range from 7 to about 15 dollars per square foot, F.O.B. the job site, with more efficient collectors being generally more expensive. Storage will add one to two dollars per square foot of collector to the system costs, and appurtenances, from 5 to 8 dollars per square foot. Including the cost for experienced labor for installation, overhead, and profit of 6 to 8 dollars per square foot, the installed system costs range from 19 to 33 dollars per square foot of collector, with an average cost of about 25 dollars per square foot.

MORTGAGE PAYMENTS

The largest portion of the annual cost of a solar system is the repayment of the loan obtained to install the system.

The loan may be based on the total building costs or separately on the solar system alone. In either event, a down payment ranging from 10 to 20 percent is required to secure the loan.

PROPERTY TAX, INSURANCE AND CREDIT ON INCOME TAXES

The annual cost of a solar system includes all the items contributing to the cash flow to operate a solar heating system. The costs include the mortgage payment and fuel costs, operating and maintenance costs, property tax, insurance on the solar system, and savings on federal and state income taxes for interest paid on the loan. In some states there are additional credits provided to state income taxes for owners of solar systems. Some of these special tax credits are substantial and impact significantly on the annual costs of the solar system.

Property taxes are based on a fraction of the assessed value of the solar system. The method of assessment, and the tax rate, vary from state to state and sometimes from county to county within the state. The office of the county treasurer can provide detailed information on method of assessed valuation and the tax rate. Usually, the assessed value is a market value of the property, and the tax rate is applied to a fraction of the assessed value. The property tax rate varies widely, from zero in some states to ten percent in others.

Insurance rates on houses with a solar system, at present, are the same as for houses without solar systems. The basic insurance rate depends upon the type of house construction and location of the building within or outside a city or town. The insurance rate for a comprehensive homeowners policy differs from that for a straight fire insurance policy, and the insurance rates for earthquake and flood damage (which are federally subsidized) are the only special insurances available for owners of buildings. The information on various insurance rates is available from local insurance agents. However, very few insurance companies have established insurance rates for solar systems. Damage to the contents of a building resulting from leaks in piping or storage tanks or damage to the solar system resulting from flooding by natural causes is based on comprehensive or flood insurance rates. Although there are many factors to be considered, the annual premium on insurance for houses with solar systems is less than one percent of the value of the house and contents, and ranges from 0.3 to about 0.6 percent.

The "savings" on state and federal income taxes for interest paid on the mortgage can be substantial, depending upon the "tax bracket" of the homeowner. Kansas has a state income tax credit up to $1000 for installing residential solar equipment. This is in addition to the Federal income tax credit.

OPERATING COSTS

The cost of operating a solar heating system, including the cost for operating the auxiliary unit in the system, is the cost of electric energy required to operate the pumps, central heat distribution fan, valves, and controller in a hydronic system, and the blowers, motorized dampers, and controller in an air system. The amount of energy used to collect, store, and distribute solar energy varies from system to system in the range from 5 to 10 percent of the total solar energy collected. The lower values in the range apply to high-head systems with large pressure drops, small systems with large pumps, and air systems with two blowers.

The operating cost for a non-solar system is much less than for a solar system. Although the blower size for distributing air to the rooms is the same, the power requirement is less for a non-solar system because the pressure drop in the system is lower. As an approximation, the energy required to operate a non-solar system is two percent of the total annual heating load.

MAINTENANCE COSTS

The maintenance costs for solar systems are unknown; there is insufficient long-term experience with various systems to indicate an appropriate annual maintenance cost. While there is one air system that has been operated continuously for 19 years, on which the maintenance cost was zero, it can be expected that all solar systems will require some maintenance during the life of the systems. For the purpose of economic analysis, the maintenance cost for the first year can be estimated to be a nominal amount, say one hundred dollars, which will be escalated annually at a selected inflation rate.

LIFE CYCLE COST ANALYSIS

A life cycle cost analysis provides a means of determining the net savings realized with a solar system as compared to a non-solar system. Annual cash flows are calculated for the systems and the difference will determine the savings possible with a solar system over the non-solar system.

The method of life cycle cost analysis enables one to determine not only if a given solar system is economical, but the optimum economical size of the solar system. By analyzing several--three at least--different collector areas for the solar system, the size of the solar system which will yield the greatest savings over a comparable number of years will be the most economical.

PREREQUISITES: SOLAR ENERGY TECHNICIAN

1. The student must have the ability to use small machine and hand tools (electric drill, saw, pliers, hammers, and chisels).
2. The student must be able to weld, or learn how to weld.
3. The student must be able to lift 100 lbs over his/her head.
4. The student must be able to read at the fifth-grade level.
5. The student must be able to work in environments of extreme cold and hot climates, from -20^{o} to $+98^{o}$F.
6. The student must be able to work in close confines.
7. The student must be physically fit and cannot have physical handicaps of the type that would restrict the student from job duties. A student must be able to work on the roof of a house or apartment without getting dizzy.
8. The student must be able to be bonded.
9. The student should have an interest in air conditioning (HVAC) and/or plumbing.
10. Student should be interested in solar as an alternate source of energy.
11. A high school diploma or GED equivalency is desired but not required.
12. Assume knowledge of basic arithmetic operations, including addition, subtraction, multiplication, and division. Must be able to read charts.
13. Normal color vision is desired, but not essential.

COURSE V: CONTROL THEORY AND APPLICATION

MODULE A: GENERAL CONTROL

UNIT I: SYSTEM CONTROLS

HANDOUT 1: INTRODUCTION

System controls are necessary to turn the system on or off as needed. Although there are several different approaches, the best solution is one that minimizes the nonsolar heat used while maintaining indoor temperatures within a comfortable range.

The basic function of the controller in a solar system is to collect as much useful heat as possible and to deliver it when needed to meet the demands of the building. The overall efficiency of the total system can be greatly influenced by the controller.

The three basic components of the controller are:

1. the sensor subsystem
2. the comparator subsystem
3. the output subsystem.

The function of the sensor subsystem is to measure temperatures and send this information to the comparator subsystem. The comparator subsystem makes the decisions regarding the control of output devices, such as the turning on and off of blowers and pumps and the opening and closing of valves and dampers.

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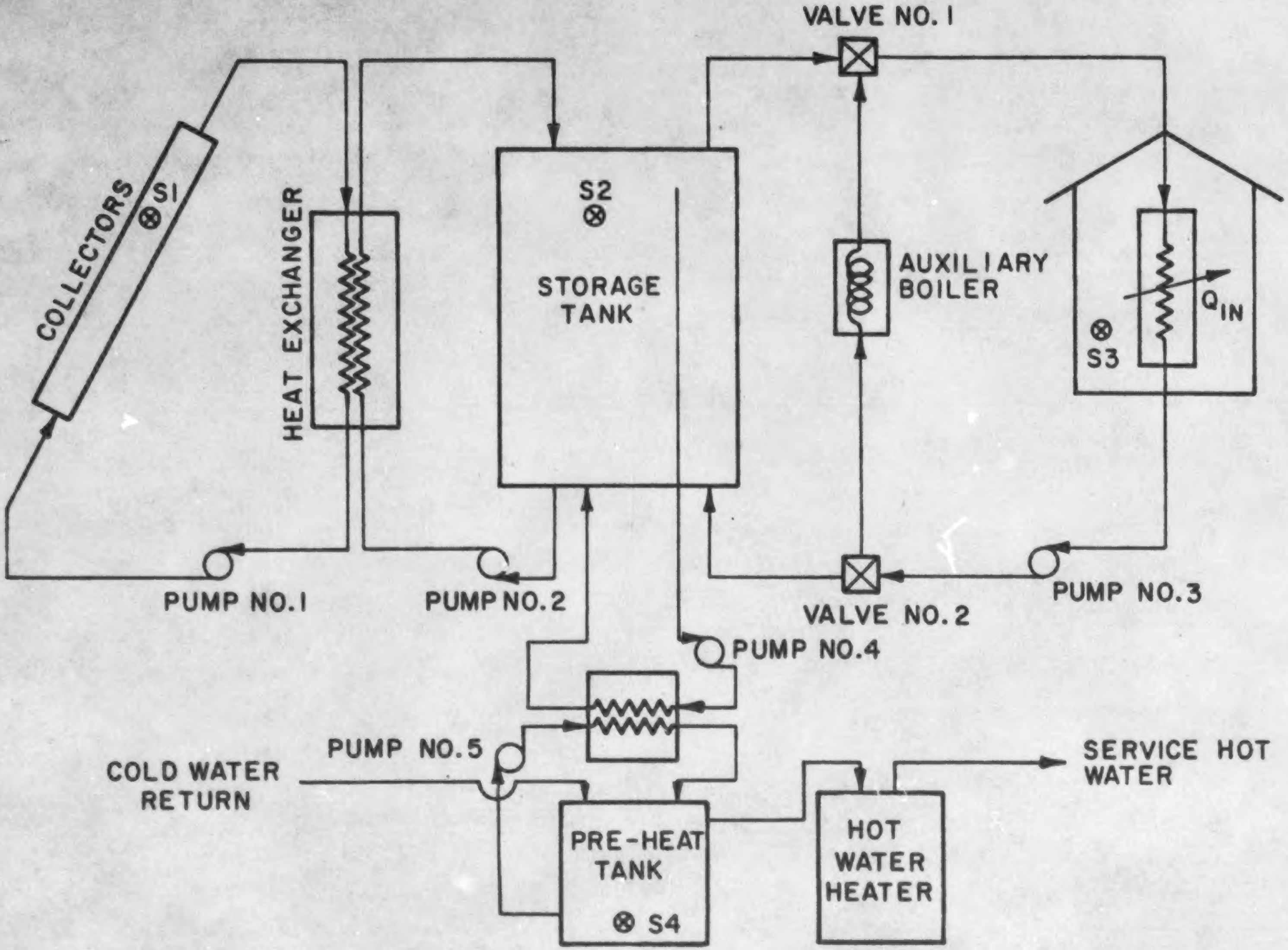
At the present time most commercially available control systems are of the "on-off" type. That is, a pump or blower is either off or on at full capacity. The decision to turn the device on or off is based on temperature differences. For example, consider the schematic representation of a solar system on the following page. The temperature sensors are indicated by S1, S2, S3, and S4. S1 measures the temperature of the fluid at the collector (or the temperature of the absorber plate, depending on the type of mounting), S2 measures the temperature of the water in storage, S3 measures the room temperature in the building, and S4 measures the temperature of the water in the preheat tank for service hot water. We shall consider how S1 and S2 are typically used in an "on-off" controller to control the collector pumps, shown as Pump Number 1 and Pump Number 2 in the diagram on the following page. When the collector temperature exceeds the storage temperature by some preset amount, ΔT_{ON}, typically about $20^{o}F$, the collector/storage pumps will be turned on by the controller. This will cause a surge of cooler fluid to circulate through the collectors, thereby lowering the collector temperature. If the decrease in collector temperature is great enough to cause the difference between the collector and storage temperatures to drop below another preset value, ΔT_{OFF}, typically about $3^{o}F$, the collector/storage pumps will be turned off. The temperature of the


VALVE NO. 1
COLLECTORS
S1
HEAT EXCHANGER
S2
STORAGE TANK
AUXILIARY BOILER
Q_{IN}
S3
PUMP NO. 1
PUMP NO. 2
VALVE NO. 2
PUMP NO. 3
PUMP NO. 4
PUMP NO. 5
COLD WATER RETURN
SERVICE HOT WATER
PRE-HEAT TANK
S4
HOT WATER HEATER

Schematic Representation of a Typical Liquid System collector will again increase rather rapidly until the collector/storage pumps will again be turned on. The amount of cycling of this type should be minimized in order to reduce wear on the pumps, pump motors, and relay contacts. If there is proper solar insolation, the collector temperature will continue to increase and the pumps will remain on until late in the afternoon. When the temperature differential has decreased again to ΔT_{OFF}, the collector/storage pumps will be turned off. This will cause the collector temperature to again increase due to the "no-flow" condition. If the temperature differential reaches ΔT_{ON}, the pumps will again be turned on. This will lead to cooling of the collectors. The collector temperature will start to increase, but if the increase is not large enough, the pumps will remain off. In brief:

1. Start collector loop pump or blower any time useful heat can be collected (approximately 20°F above storage temperature).
2. Stop collector loop pump or blower when useful heat cannot be collected (3 to 4°F above storage temp.).
3. Furnish heat energy for domestic hot water, space heating, cooling, etc., from collectors or storage, as applicable, if available.
4. If sufficient solar heat energy is not available, operate auxiliary equipment.
5. If more heat is being collected than can be utilized, operate heat rejection equipment.

6. In some systems, the collector loop pump is started to furnish heat to the collector array to prevent freezing during non-collecting periods.

7. In other systems, valves are actuated to drain the collectors as the temperature approaches freezing.

COURSE V: CONTROL THEORY AND APPLICATION

MODULE A: GENERAL CONTROL

UNIT I: SYSTEM CONTROLS

HANDOUT 2: CONTROL HARDWARE

The solar system controls consist of power relays which switch electric valves and pumps in the liquid system, or blowers and dampers in the air system, and auxiliary heating units in both systems, in response to temperatures or temperature differences. Controls for solar systems fundamentally serve the same functions as in conventional HVAC systems; however, there are more control functions in solar systems and also there are interlocks which prevent undesirable or hazardous sequences of operation.

A solar system supplier should provide the required control hardware, or at least specify it, along with explicit wiring instructions. Building a control system at the site should be avoided unless experience in this practice is available.

THERMOSTAT

A two-stage heat, indoor thermostat is recommended for residential solar heating systems, and a two-stage heat, one-stage cool type is recommended for solar heating and cooling systems. Variations will feature on, off, or automatic fan control to circulate the room air, and heat, cool, or automatic switches from heating to cooling or vice-versa to meet the need.

The single-stage cooling provides indoor space temperature control, when cooling is required. There is a deadband, which is a small range in temperature between start and stop signals given to the controller, which in turn controls the cooling system. The deadband for most thermostats is about 5°F. The heating operation is a bit more intricate. Upon demand for heat, the first stage calls for the solar system to provide heat. If the building heat loss is greater than the solar system can provide, the temperature in the building will continue to drop to stage two and the auxiliary system will be called upon to provide heat. The auxiliary system can provide enough heat for the building by itself or in combination with the solar system to raise the temperature in the room to the upper temperature limit of stage one, which stops the heating system. The upper temperature deadband is nominally about 2°F.

The thermostat is the only control with which the occupant needs to be concerned. Once the occupant sets the winter comfort control level to, say, 68°F, and the summer comfort level to 75°F, or other suitable temperatures, no further adjustment or temperature selection is needed for any other control in the heating and/or cooling system.

The thermostat should be installed after the standard installation procedures. Normally the instructions are supplied with the thermostat. The thermostat should be located at a position such that the temperature at its point of location is representative of the average temperature within the enclosure.

TEMPERATURE SENSORS

Many types of temperature sensors are available that can be used in the control subsystem--thermocouples, thermistors, silicon transistors, bimetallic elements, and liquid or vapor expansion units. Liquid or vapor expansion units are seldom used because other temperature sensors are more durable and dependable. Thermocouples are often used for temperature measurement. However, they are not often used in controls because the voltage output is low, in the millivolt range, and without amplification the voltage is insufficient to be used in controls.

Thermistors and silicon transistors are used in the control subsystem because the voltage outputs from these sensors are in the 0 - 10 volt range and are high enough to serve the control functions. The voltage outputs from thermistors are nonlinear, and calibration circuitry must be provided for the nonlinearity. The voltage outputs from silicon transistors are linear in the normal operating temperature range of solar heating and cooling systems, and provide for simpler circuitry to control the system.

COURSE V: CONTROL THEORY AND APPLICATION

MODULE A: GENERAL CONTROL

UNIT I: SYSTEM CONTROLS

HANDOUT 3: SENSOR LOCATION

The locations of temperature sensors are not necessarily critical, but there are some precedent locations. Temperature sensors are needed to measure the air or liquid temperature as it exists from the collector, in the solar storage tank, or rock bed, and in the preheat water tank. The sensor in the conditioned space is the thermostat.

The sensor which measures the fluid temperature at the collector outlet can be located in the manifold which collects the fluid from the total array of collectors. It is desired that the sensor be in contact with the fluid, but it is acceptable for the sensor to be in contact with the pipe, provided there is good thermal contact of the sensor with the pipe. If the sensor is fastened to the outside of the outlet pipe, the sensor whould be well insulated so that it does not lose the heat to the surroundings and register a low temperature. It is important to locate the sensor near the outlet so that it can register the fluid temperature when the sun is heating the collector but the fluid is not circulating. Sensors in the outlet manifold will register the increase in temperature, but the sensor located far from the manifold will not, and useful energy cannot then be collected. Wherever the sensor is placed, the characteristics should be checked out when the system is put into operation.

The sensor in the storage tank should be located near the bottom third inside the tank. When there is no fluid circulation, the temperature at the top of the tank will be slightly higher than the bottom, but while the fluid is in circulation, the fluid in the tank is usually well mixed and the temperature will be uniform.

The location of the sensor in the preheat tank should be close to the top one-third of the tank. If it were located near the bottom, the temperature at the top could be several degrees hotter. Also, when hot water is used in the household, cold water enters the preheat tank near the bottom. While the preheat tank would be thermally mixed when the pump is started, frequent cycling could result from the sensor registering locally cold water temperature. For air system, the cycling is not particularly damaging because only one pump for the preheat cycle is involved. However, for the hydronic system, two pumps will be put into operation, and frequent cycling can be wasteful of electric energy. In both air and liquid systems, more heat would be wasted than necessary from the pipes and heat exchangers because of frequent cycling.

The sensor in the pebble-bed should be located at the bottom, or outlet, end of storage. When heat is being stored, the bottom, or outlet, end of storage will determine if storage is full. In brief:

1. Air systems
    - A. collector inlet
    - B. collector outlet
    - C. storage (bottom of rock bed)
    - D. conditioned space
2. Liquid systems
    - A. collector outlet
    - B. storage (bottom 1/3 of tank)
    - C. conditioned space
    - D. domestic hot water pre-heat tank (top 1/3 of tank)

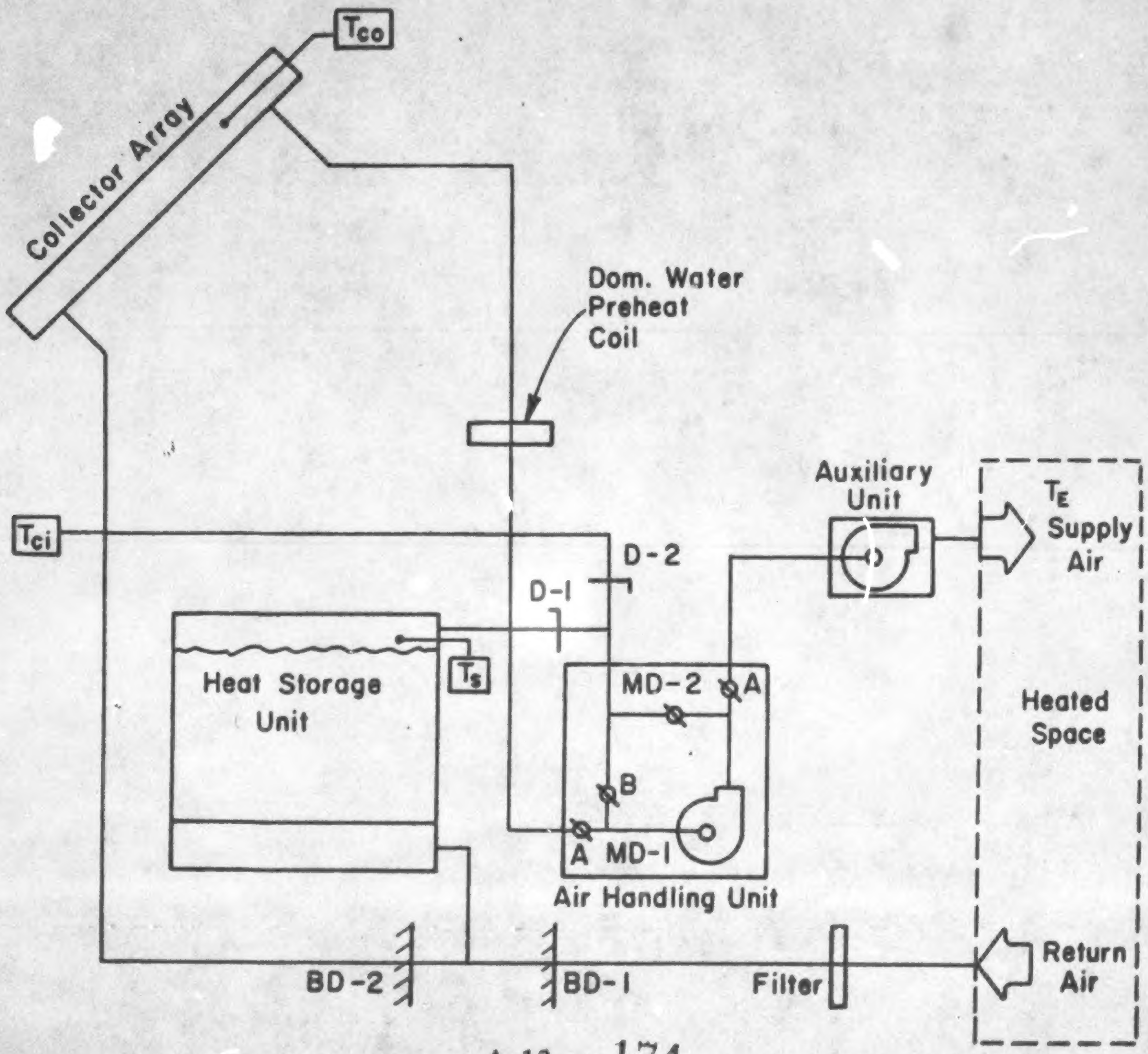
COURSE V: CONTROL THEORY AND APPLICATION

MODULE A: GENERAL CONTROL

UNIT II: TYPICAL CONTROL SUBSYSTEM

HANDOUT 1: AIR SYSTEM

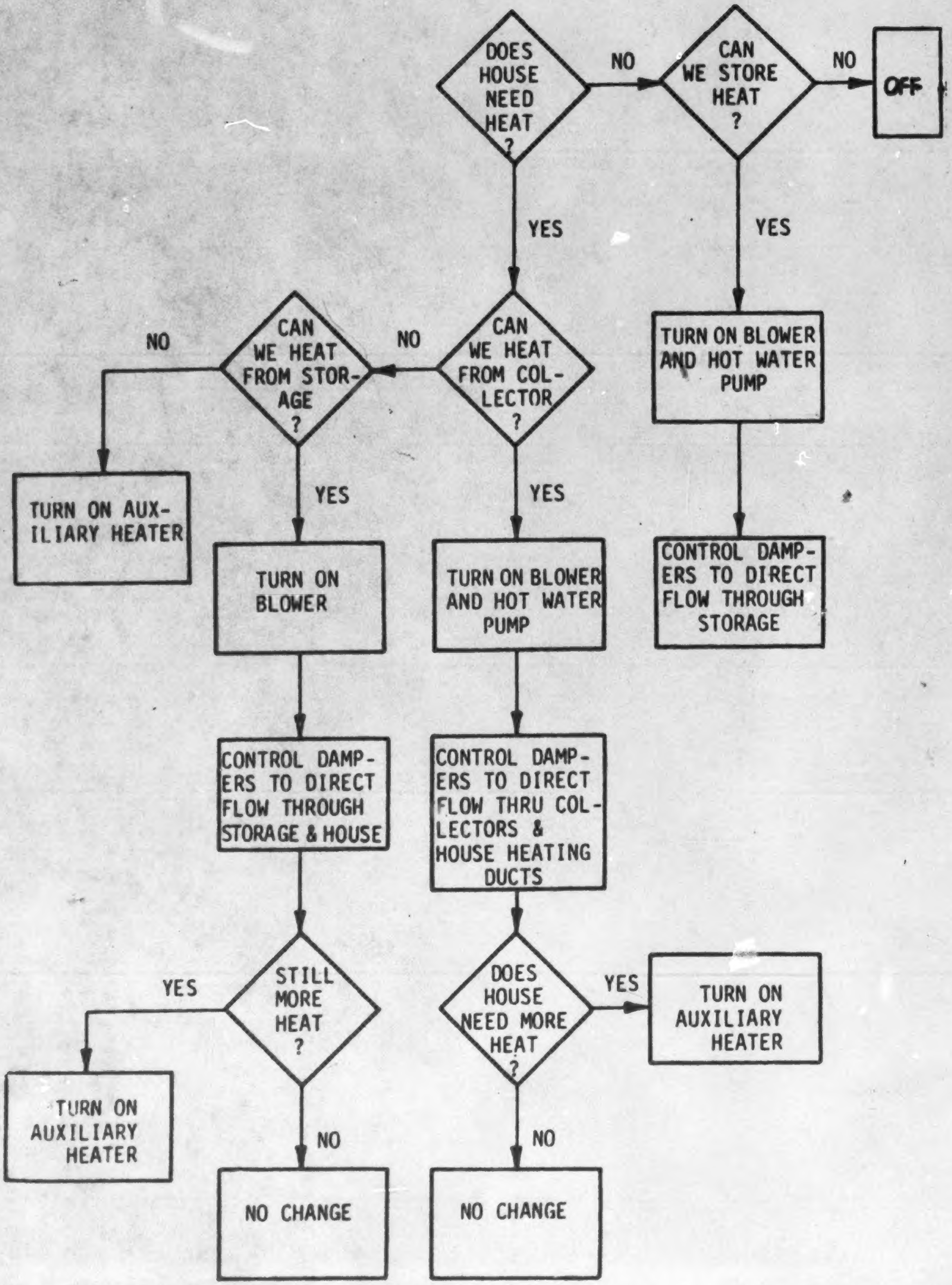
A sketch of a typical configuration for an air system is shown below. The temperature sensors are indicated by


T_{co}
Collector Array
Dom. Water Preheat Coil
T_{ci}
Auxiliary Unit
T_E
Supply Air
D-2
D-1
Heat Storage Unit
T_s
MD-2
A
B
A MD-1
Air Handling Unit
Heated Space
Return Air
BD-2
BD-1
Filter

T_{ci}, T_{co}, T_S and T_E. T_{ci} measures the collector inlet temperature, T_{co} measures the collector outlet temperature, T_S measures the storage temperature, and T_E measures the enclosure temperature. BD-1 and BD-2 represent backdraft dampers, D-1 and D-2 represent manual dampers, and MD-1 and MD-2 represent motorized dampers. The function of the controller is to operate the blowers and the motorized dampers to collect and distribute heat for the house. A flowchart of the control strategy is shown on the following page.

The first decision to be made by the controller depends on whether or not the house needs heat. This is decided by comparing the present temperature with the desired temperature. If the temperature measured by the temperature sensor in the house indicated that the house needs no heat, then the controller must decide whether or not heat can be stored. This is decided by comparing the collector inlet temperature, T_{ci}, with the collector outlet temperature T_{co}. If T_{co} is not greater than T_{ci}, then obviously there is no heat being collected by the collector and we would not want to circulate the air through the collectors. If T_{co} exceeds T_{ci}, then there is useful energy available and the controller will turn on the blower and the hot water pump and control the dampers to direct the flow through the storage.

If the house needs heat, then the controller must decide whether that heat can be supplied from the collector or from storage. These determinations are again made by comparing


DOES HOUSE NEED HEAT ?
NO
CAN WE STORE HEAT ?
NO
OFF
YES
YES
CAN WE HEAT FROM STORAGE ?
NO
CAN WE HEAT FROM COLLECTOR ?
NO
TURN ON BLOWER AND HOT WATER PUMP
TURN ON AUXILIARY HEATER
YES
YES
TURN ON BLOWER
TURN ON BLOWER AND HOT WATER PUMP
CONTROL DAMPERS TO DIRECT FLOW THROUGH STORAGE
CONTROL DAMPERS TO DIRECT FLOW THROUGH STORAGE & HOUSE
CONTROL DAMPERS TO DIRECT FLOW THRU COLLECTORS & HOUSE HEATING DUCTS
YES
STILL MORE HEAT ?
DOES HOUSE NEED MORE HEAT ?
YES
TURN ON AUXILIARY HEATER
TURN ON AUXILIARY HEATER
NO
NO
NO CHANGE
NO CHANGE

Flow Chart of Control Strategy

temperatures. If T_{co} is not greater than T_{ci}, then obviously we cannot supply the heat from the collector. Question is, can the heat be supplied from storage? This is decided by comparing the storage temperature, T_S, with the reference temperature, T_{SR}, which is nominally set at 100°F. If T_S is not greater than T_{SR}, then we can not heat from storage. However, if T_S exceeds T_{SR}, then the controller will turn on the blower and control the dampers to direct the flow through the storage container and to the house by providing heat to the enclosure. The enclosure temperature may, of course, continue to decrease due to high heat losses from the house. If the enclosure temperature, T_E, drops below the reference temperature, T_{R2}, then it is clear that still more heat is needed. If this happens, the controller will turn on the auxiliary heater.

If the controller decided that heat could be supplied from the collector, that is, T_{co} is greater than T_{ci}, then the controller will turn on the blower and the hot water pump and control the dampers to direct the flow through the collectors and then to the house heating ducts. It is still possible that this may not supply necessary heating to the house, and consequently the controller must compare the enclosure temperature with the second reference temperature to decide whether or not the auxiliary heater must be turned on.

PREREQUISITES: SOLAR ENERGY TECHNICIAN

1. The student must have the ability to use small machine and hand tools (electric drill, saw, pliers, hammers, and chisels).
2. The student must be able to weld, or learn how to weld.
3. The student must be able to lift 100 lbs over his/her head.
4. The student must be able to read at the fifth-grade level.
5. The student must be able to work in environments of extreme cold and hot climates, from -20° to +98°F.
6. The student must be able to work in close confines.
7. The student must be physically fit and cannot have physical handicaps of the type that would restrict the student from job duties. A student must be able to work on the roof of a house or apartment without getting dizzy.
8. The student must be able to be bonded.
9. The student should have an interest in air conditioning (HVAC) and/or plumbing.
10. Student should be interested in solar as an alternate source of energy.
11. A high school diploma or GED equivalency is desired but not required.
12. Assume knowledge of basic arithmetic operations, including addition, subtraction, multiplication, and division. Must be able to read charts.
13. Normal color vision is desired, but not essential.

COURSE VI: MATERIALS AND FABRICATION

MODULE A: BASIC MATERIALS

UNIT I: Tools and Information Requirements A-1

Handout 1: Tool List A-1

2: Electric Control Information Outline A-5

3: Basic Symbols A-7

A. Plumbing A-7

B. Electric A-8

UNIT II: Solar System Materials A-10

Handout 1: Partial List of Equipment and Materials A-10

MODULE B: FABRICATION

UNIT I: Basic Welding and Soldering B-1

Handout 1: Safety B-1

2: Techniques B-2

UNIT II: Typical Solar System B-6

Handout 1: Installation Factors B-6

2: Installing Collectors B-9

3: System Hook-up B-12

4: System Checkout B-15

MODULE C: AIR DISTRIBUTION

UNIT I: Ducting C-1

Handout 1: Introduction C-1

2: Duct System Design C-4

3: Duct Insulation C-6

COURSE VI: MATERIALS AND FABRICATION

MODULE A: BASIC MATERIALS

UNIT I: TOOL AND INFORMATION REQUIREMENTS

HANDOUT 1: TOOL LIST

HAND TOOLS

A. Screwdrivers
    1. Blade
    2. Phillips
B. Pliers
    1. Slip joint
    2. Long nose
    3. Diagonal cutters
C. Wrenches
    1. Open-end
    2. Boxed-end
    3. Combination
    4. Adjustable
D. Refrigerant ratchet wrench
E. Allen key set
F. Hammers
G. Nut drivers
H. Hacksaw
J. Socket set

TOOLS FOR WORKING WITH TUBING

A. Flaring tool

B. Tube cutters

C. Swaging punches

D. Spring benders

E. Lever type tube benders

F. Pinch-off tool

OXY-ACETYLENE TORCH

A. Description

B. Procedure for safe operation

C. Flame adjustment

SERVICE VALVES

A. Types

B. Operation

GAUGE MANIFOLD

A. Care

B. Use

C. Operation

TOOLS FOR WORKING WITH STEEL PIPE

A. Pipe vise

B. Pipe cutter

C. Pipe dies

MEASURING DEVICES

A. Basic elements
    1. Liquid expansion
    2. Bi-metallic
    3. Bourdon tube
B. Temperature
C. Pressure
D. Vacuum
E. Dimensions

PIPE, TUBE, AND FITTINGS

A. Steel, copper, aluminum and plastic
B. Nomenclature
C. Size determination

SOLDERING AND BRAZING

A. Copper to copper
B. Copper to aluminum
C. Copper to steel
D. Aluminum to aluminum

VACUUM PUMPS

A. Purpose
B. Types
C. Care and use

PLASTIC PIPE

A. Method of assembly

B. Support

LEAK CHECKING

A. Pressure

B. Halide torch

C. Soap bubbles

D. Electronic

COURSE VI: MATERIALS AND FABRICATION

MODULE A: BASIC MATERIALS

UNIT I: TOOLS AND INFORMATION REQUIREMENTS

HANDOUT 2: ELECTRIC CONTROL INFORMATION OUTLINE

All active solar systems utilize pumps and/or blowers to circulate heat transfer fluids. The operation of these pumps and blowers is controlled by the control system. A good working knowledge of electric motors, control hardware, and control circuitry is essential to the successful performance of solar systems.

INTRODUCTION TO THE ELECTRIC CONTROL CIRCUIT

1. Conductors and insulators
2. Circuit requirements: source, load, path of conductance
3. Alternating and direct current
4. Units of measurement: volts, amperes, ohms
5. Ohm's law

BASIC ELECTRIC CONTROL HARDWARE

1. Measuring instruments for field use: volt-ammeter and ohm-meter
2. Manually operated switches
3. Temperature and pressure operated switches
4. Typical relays and contactors used in this field
5. Fuses and circuit breakers
6. Low voltage transformers

7. Typical loads: motors, heaters, lights
8. Wires and wire sizes

BASIC CONTROL CIRCUITRY

1. Purpose of controls
2. Switching and contact terminology
3. Relay switching
4. Series, parallel, and series-parallel circuits
5. Control transformer operation
6. Operating load and safety and control circuits
7. Lock-in and lock-out circuits
8. Multiple control point switching of loads

INTRODUCTION TO SCHEMATIC SYMBOLS AND WIRING DIAGRAMS

1. Hardware symbols
2. Application of symbols to wiring diagrams
3. Reading schematic wiring diagrams

ELECTRIC MOTORS AND MOTOR STARTING COMPONENTS

1. Motor construction
2. Motor types and characteristics
3. Motor terminal identification
4. Motor capacitors: starting and running
5. Starting relays: hot wire, current, potential

COURSE VI: MATERIALS AND FABRICATION

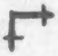
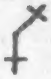
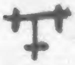
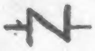
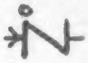
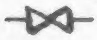
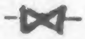
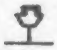
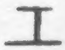
MODULE A: BASIC MATERIALS

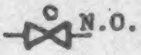
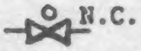
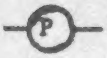
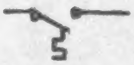
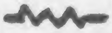
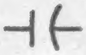
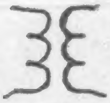
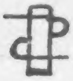
UNIT I: TOOL AND INFORMATION REQUIREMENTS

HANDOUT 3: BASIC SYMBOLS

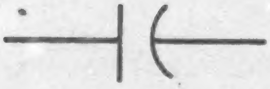
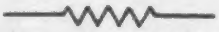
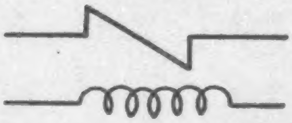
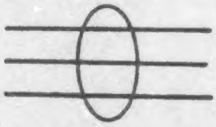
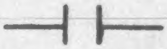
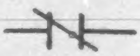
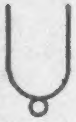
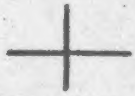
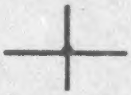
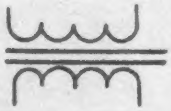
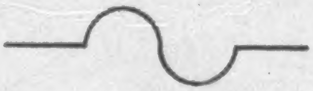
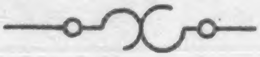
PLUMBING

Schematic symbols for common items are shown below. Shorthand notations denoting how the plumbing connections are made have been omitted.

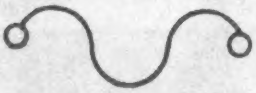
	Elbow, 90 degrees
	Elbow, 45 degrees
	Tee
	Check valve
	Swing check valve
	Gate valve
	Globe valve
	Pressure relief valve
	Float-type air relief valve

	Normally open solenoid valve
	Normally closed solenoid valve
	Pump
	Thermostat switch
	Resistor
	Capacitor
	Transformer
	Relay coil

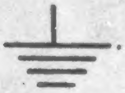
ELECTRIC

Capacitor		Resistor	
Coils		Multiple Conductor Cable	
Contacts	 Open  Closed	Thermocouple	
Conductors	 Crossing  Junction	Transformer	
Fuse		Thermal Overload	

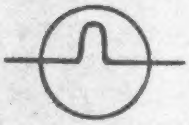
Fusible Link



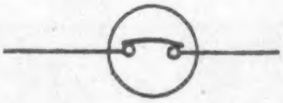
Ground Connection



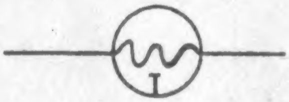
Light



Bimetal Switch



Thermistor



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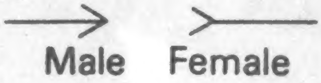
Male
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COURSE VI: MATERIALS AND FABRICATION

MODULE A: BASIC MATERIALS

UNIT II: SOLAR SYSTEM MATERIALS

HANDOUT 1: A PARTIAL LIST OF EQUIPMENT AND MATERIALS

1. Solar collectors
2. Liquid storage tanks
3. Pre-heat tank
4. Conventional furnace
5. Hot water boiler
6. Load heat exchanger
7. Collector loop heat exchanger
8. Domestic hot water heat exchanger
9. Pumps
10. Solar air movers
11. Blowers
12. Heat rejection units
13. Conventional water heater
14. Expansion tanks
15. Automatic air vents
16. Air conditioning units
17. Controls
    - A. Room thermostat
    - B. Control panel

    - C. Sensors
    - D. Damper actuators
    - E. Valve actuators

18. Rock bed storage units
    - A. Enclosure lumber
    - B. Thermal insulation
    - C. Pebble support grate
    - D. Pebbles

19. Ductwork
    - A. Sheetmetal
    - B. Registers, grilles, and diffusers
    - C. Duct liners
    - D. Thermal insulation
    - E. Dampers
    - F. Support materials
    - G. Flexible connections

20. Piping
    - A. Pipe
    - B. Fittings
    - C. Valves
    - D. Thermal insulation
    - E. Support brackets

21. Collector supports

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COURSE VI: MATERIALS AND FABRICATION

MODULE B: FABRICATION

UNIT I: BASIC WELDING AND SOLDERING

HANDOUT 1: SAFETY

1. Always extinguish a torch whenever it is not in your hands.
2. The torch hand valve should only be turned with the fingertips.
3. If a torch backfires, find the trouble and remedy it before continuing to use the torch.
4. Be careful that a torch is not directed toward another person while it is being lighted.
5. Safety goggles should be worn to protect the eyes and reduce glare.
6. Use a spark lighter for lighting the torch.
7. Be sure that no combustible material is in the area in which a torch is being lighted.
8. Use only fireproof materials for the support of articles being soldered or brazed.
9. Good ventilation is essential to eliminate health hazards which are presented by toxic metal and flux fumes.
10. Be sure that there are no flammable fumes such as gasoline, acetylene or other flammable gasses present where soldering or brazing is being performed.
11. Soldering or brazing with or on alloys containing cadmium, beryllium, tellurium, lead, mercury, antimony, arsenic, bismuth, and their compounds can be extremely hazardous. Fluxes containing fluoride compound are also toxic.
12. A common hazard when soldering or brazing is exposure of the skin, eyes, and clothing to acid fluxes. Always work in a way that flux will not be spilled on the skin or clothing. If fluxes do come into contact with the skin, the skin should be washed thoroughly with soap and water.
13. Eating or storing of lunches should not be permitted in the work area, and workers should wash both hands and faces before eating, smoking or leaving from work.

COURSE VI: MATERIALS AND FABRICATION

MODULE B: FABRICATION

UNIT I: BASIC WELDING AND SOLDERING

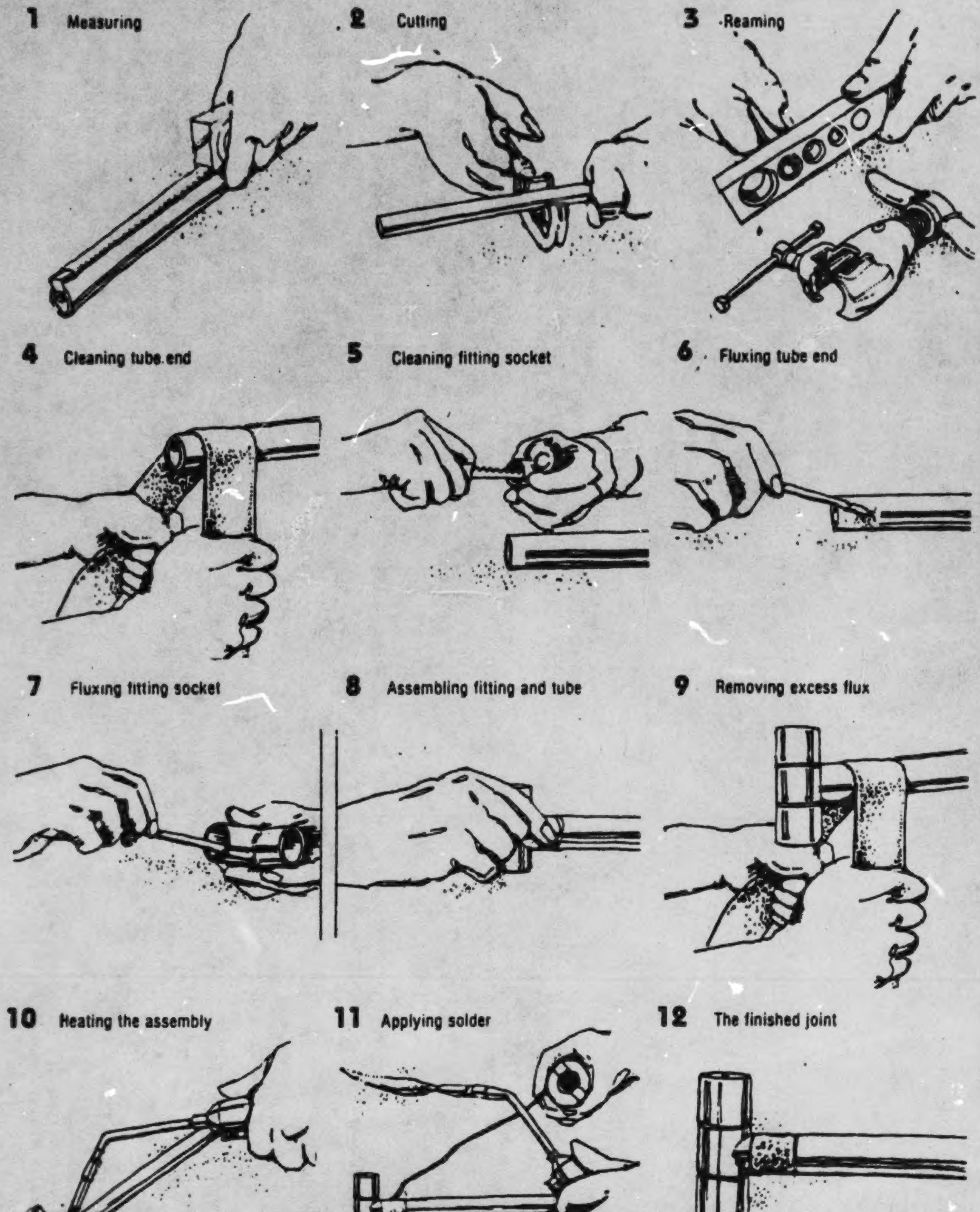
HANDOUT 2: TECHNIQUES

CLEANING

After cutting and deburring, the tubing and fitting must be properly cleaned to remove dirt, oil, grease and oxides. First, clean with a solvent and then use a fine grit emery paper to clean the fitting and the end of the tubing (see following page). Clean the fitting all the way down to, and including, the bottom of the socket where the ledge starts. Clean the tubing ½ to ½ inch more than the depth of the socket, or 3/4 to 1 inch from the end of ½ inch diameter tubing. Do not remove more metal than is necessary to get a clean-looking surface. Do not handle surfaces after cleaning.

FLUXING

Flux protects the cleaned metal from oxidizing when the parts are heated, and should be applied immediately after cleaning. Fluxes generally used are available in paste form and can be applied sparingly in a thin, even layer to the tubing and fitting. Be sure to use a clean brush, and cover only those areas to be soldered or brazed. In the case of refrigeration joints, do not flux the inside of the fitting.



1 Measuring

2 Cutting

3 Reaming

4 Cleaning tube end

5 Cleaning fitting socket

6 Fluxing tube end

7 Fluxing fitting socket

8 Assembling fitting and tube

9 Removing excess flux

10 Heating the assembly

11 Applying solder

12 The finished joint

Making a Solder Joint

Assemble the parts immediately after fluxing, making sure the tubing is inserted into the fitting until it bottoms out. Where, possible, revolve the fitting once or twice on the tubing to spread the flux uniformly.

SUPPORTING THE ASSEMBLY

After assembly and correct alignment, the assembly should be adequately supported so that expansion and contraction will not be restricted and there is not any strain on the joints.

HEATING AND FLOWING THE ALLOY

Start by using a torch tip that delivers a relatively small flame size; then a larger flame or even a multiple-tipped torch. Shorter heating periods may be used as proficiency improves. Adjust the torch for a slightly reducing flame. Heat the tubing first, directing the flame slightly away from the fitting. Try to keep the flame away from the fluxed and cleaned areas to minimize oxidation. After heating the tube momentarily, alternate the flame between the tubing and fitting. Do not melt the alloy or solder with the flame. It will melt by contact with the tubing when the proper temperature is reached. When the alloy or solder begins to melt, move the flame to the corner of the fitting, rotating it as necessary to heat the entire perimeter, and feed the alloy or solder into the joint all the way around the tube. Remove the flame once the joint is full. Overheating may damage the joint.

CLEANING

After the alloy or solder has set, apply a wet brush or swab to the joint to crack and wash off the flux. All flux should be removed for inspection and pressure testing. Use a wire brush if necessary. Be careful not to move the assembly while the alloy or solder is solidifying, or a cracked joint will result.

COURSE VI: MATERIALS AND FABRICATION

MODULE B: FABRICATION

UNIT II: TYPICAL SOLAR SYSTEM

HANDOUT 1: INSTALLATION FACTORS

A good installation is just as important as the system design. In fact, the success or failure of a solar system may well be determined by the quality of the installation.

1. Collectors
    - A. Roof mounted
        - a. Structural strength
        - b. Water proofing
    - B. Free standing supports
    - C. Aesthetic appearance
2. Heat Storage
    - A. Rock beds
        - a. Construction
        - b. Support
    - B. Liquid tanks
        - a. Support
        - b. Insulation
3. Equipment
    - A. Domestic hot water preheat tank
    - B. Auxiliary furnace

- C. Solar air movers
- D. Access for service

4. Hydronic Systems
    - A. Piping
    - B. Heat exchangers
        - a. Liquid to liquid
        - b. Air to liquid
    - C. Pumps
    - D. Expansion tanks
    - E. Air vents
    - F. Strainers
    - G. Balancing valves
    - H. Regulators
    - I. Pressure and temperature relief valves
    - J. Control valves
    - K. Provisions for measuring
        - a. Flow
        - b. Pressure
        - c. Temperature
    - L. Thermal insulation
    - M. Antifreeze solutions
5. Air Distribution
    - A. Ductwork
        - a. Sheetmetal
        - b. Fiberglass

- B. Supply and return devices
  - a. Registers
  - b. Grilles
  - c. Diffusers
- C. Insulation
  - a. Thermal
  - b. Sound control

6. System Loading
   - A. Dead loads
   - B. Live loads
   - C. Wind loads
   - D. Snow loads
   - E. Seismic loads
   - F. Hail loads
   - G. Dynamic loads (tracking)
   - H. Thermal cycling
   - I. Collector cover loads
7. Masonry Considerations
   - A. Chimneys
   - B. Footings and foundations
   - C. Tank walls and covers

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COURSE VI: MATERIALS AND FABRICATION

MODULE B: FABRICATION

UNIT II: TYPICAL SOLAR SYSTEM

HANDOUT 2: INSTALLING COLLECTORS

The home is a collector in an effective passive design. However, most new homes and retrofits, at this time, use flat-plate collectors. These collectors are usually either placed on the ground or on the roof. The roof mounting is considered below.

1. Prepare collector mounting foundation
   - A. Mark points on roof where collector mounts are to be placed
   - B. Clean area of all loose roofing materials
   - C. Drill holes into roofing joints through roof
   - D. Lay in flashing material or roofing mastic/tar or both according to plans
   - E. Put collector mounting foundation in place and flash around it
2. Construct collector mountings
   - A. Obtain blueprints or plans of collector mountings
   - B. Obtain material needed per plan (assess here wood mountings).
   - C. Attach vertical supports to foundation
   - D. Attach angled supports (angle = tilt) to foundation
   - E. Attach angled supports to vertical supports
   - F. Attach all vertical supports together with wood members (2 x 4)

G. Paint mountings

3. Mount each collector

   A. Obtain collectors from manufacturer

   B. Raise collector onto roof

   C. Place collector on mounting being careful not to damage copper heads or mountings

   D. Fasten collector to mounting per blueprints

4. Install each temperature sensor

   A. Obtain thermistor or other sensing device per plan

   B. If well type temperature sensor is used, insert probe in temperature well, being careful not to damage probe

   C. If strap-on type probe is used, attach probe to collector pipe storage tank with tape or mechanical clamps insuring that sensing points are firmly touching area to be measured.

5. Connect dampers, valves, safety devices as required by system design

   A. Obtain necessary materials (i.e. air vents, relief valves, etc.)

   B. Determine placement of air vents at all high points in system or per blueprints

   C. Determine relief valve placement at highest point in system

   D. Using 3/4" copper FPT adapter, install air vents

   and relief valves using teflon tape on threads

6. Connect manifolds and collector pipelines

   A. Obtain blueprint and material, i.e., pipe, elbows, couplings, etc.

   B. Measure distances between collector

   C. Cut pipe length accordingly

D. Clean and flux pipe (copper).

E. Connect pipe between collector

F. Solder pipe fittings

G. Insure that pipe lines are sloped such that air vents are at high points

COURSE VI: MATERIALS AND FABRICATION

MODULE B: FABRICATION

UNIT II: TYPICAL SOLAR SYSTEM

HANDOUT 3: SYSTEM HOOK-UP

The scheduling of sequential and concurrent activities for installing solar heating systems during new home construction, depends upon the type of system to be installed. If attention is not given to the sequence of assembly, unnecessarily difficult situations could result. Some of the tasks that are involved follow.

1. Mount major solar system components: heat exchangers, air handlers, pumps, blowers, domestic hot water tanks, etc.
    - A. Select location for air handler.
    - B. Construct plenum of wood or sheet metal for return air to match dimensions of air handler, or mount return air box (sheet metal) and attach collar. Install return air grill. Insulate plenum.
    - C. Place or suspend air handler. If suspended, hang with sheet metal straps. If installed vertically, fasten down with screws over return air plenum.
    - D. Install pumps. If 1/12 H.P. or under, support with plumbing, insuring plumbing is well anchored. If greater than 1/12 H.P., nail mounting block to

suitable wall, etc. and fasten pump to block with lag or machine screws. Use dielectric unions where cast iron pump is connected to copper lines.

E. Set domestic water heater tanks in place. If tank is placed on upper story, install sheet metal drip pan underneath.

2. Connect all solar components with pipelines as required by system design.

   A. Connect return air box (if used) to return air plenum with suitable duct material. Also connect supply air plenum to supply boxes (boots), using Y's and appropriate sized duct. Tape all joints and insulate if not using pre-insulated duct. Set supply air registers.

3. Install system controls and make connections to sensors.

   A. Fasten controls to wall or other location.

   B. Connect thermostat wire from sensors to terminal strip or to control leads with wire nuts.

   C. Connect all relays, thermostats, in manner above.

4. Flush, fill, and purge (liquid system).

   A. Fill system in manner prescribed by plans.

   B. Check all pumps to insure that they are circulating water and not cavitating as a result of air in the water lines. Bleed off air through air bleeds of by loosening fittings.

   C. Turn pumps on and off several times to insure system is free of air and that pumps are not cavitating.

5. Make electrical connections.
   A. Attach conduit to control box and to junction box (if required).
   B. Feed wire (of proper gauge) through conduit.
   C. Connect leads in junction box (insure power is off) using wire nuts. Also connect leads at control to terminal strip or to appropriate leads.
   D. Secure covers to junction box and control box.

COURSE VI: MATERIALS AND FABRICATION

MODULE B: FABRICATION

UNIT II: TYPICAL SOLAR SYSTEM

HANDOUT 4: SYSTEM CHECKOUT

It is advisable to check the entire solar system after installation. The control system should be subjected to a "dry" run through the full sequence of modes. Some tasks that are involved follow.

1. Leak test all pipelines.
    A. Inspect all joints in piping for moisture.
    B. Drain and solder any faulty joints.
2. Check out the system powered components.
    A. Insure power is delivered to system components.
    B. Place system in all possible operating modes by manually switching control and/or shorting sensor wires.
    C. Check operation of pumps, automatic valves and other components in all modes to insure their operation complies with the intended mode of operation.
    D. Return control overrides to normal position.
3. Insulate pipelines as necessary.
    A. Apply pipe insulation according to method appropriate to insulation being used (hot water pipe only).

    B. Cover, tape, or seal any insulation exposed to weather.

4. Calibrate and test solar temperature differential controls.
    A. If control system is factory calibrated, inspect operation of system under various temperature and insolation conditions. Insure that system is operating in proper modes.
    B. If control is not factory calibrated, test by immersing sensors in water at various temperatures. Monitor water temperature with thermometer and check differential on and off temperatures and high or low limit functions. Use VOM to check position of relays.
5. Test system operation modes.
    A. Observe system operation under different temperature and insolation conditions. Use overrides where necessary to simulate operation conditions.
    B. Check position of all valves and operation of pumps and relays in all modes.
6. Balance flow controls as specified.
    A. Using flow meters or collector temperature monitors, adjust flow controls to achieve balanced flow rate or uniform temperature at all collectors.
    B. Flow control valves should be wide open and then gradually closed to achieve proper balance and flow rate.

COURSE VI: MATERIALS AND FABRICATION

MODULE C: AIR DISTRIBUTION

UNIT I: DUCTING

HANDOUT 1: INTRODUCTION

In a central heating or central cooling system, the delivery system for the conditioned air is through duct work.

The specific type of duct system used depends upon the type of structure, the equipment location and the layout of the building. Ideally, the furnace should be located near the center of the house. This will eliminate long runs of ducts, which is more important since conditioned air passing through long ducts will lose or gain considerable heat before reaching its destination. Also, long ducts increase the incidence of friction between the air and the sides of the ducts, which causes more energy loss.

Single-story houses may have the ductwork terminating in registers delivering air from either the floor, walls or the ceiling. However, it is recommended that overhead distribution be used only in mild winter climates unless some provision is made to heat the floors in a cold climate.

CALCULATION OF DUCT SIZE

Duct sizes are determined according to airflow rates in CFM (cubic feet per minute). Size is determined by the amount of air that is required to either heat or cool a room. The general formula is $S/sf = \frac{V}{AF}$ where S is the size in square feet, V is the volume of air required and A/F is the air flow in feet per minute (usually 600 fpm in the average room). V is determined by several factors including heat loss temperature of the air coming off the furnace or air conditioner and the overall volume of the room. Generally speaking, air conditioning ducts must be larger than heating ducts. Ducts are commonly rectangular or circular in cross section, and are usually designed for velocities of 150 to 1500 feet per minute (fpm).

Cost of duct work varies. As a rule of thumb, at present prices, ductwork is estimated at \$75 - \$100 per room register.

TYPES OF DUCTS

Ducts are usually made of:

- Galvanized steel sheet
- Black-iron sheet
- Stainless-steel sheet
- Aluminum sheet
- Fibrous glass sheet

Heating ducts are usually 6" in diameter and cooling ducts 8".

The common functions of ducts and their operating specifications are:

Air intake from outside 500-1200 CFM

Air washers (dust romovers)	500- 600 CFM
Branch ducts and risers	500-1800 CFM
Exhaust risers	500-1800 CFM
Heater corrections	700-1400 CFM
Humidifiers	500- 600 CFM
Main Exhaust ducts	900-1500 CFM
Main Ventilating ducts	500-1500 CFM
Supply grilles near floor	150- 250 CFM
Supply openings	350- 500 CFM
Supply registers and grilles	250- 450 CFM

COURSE VI: MATERIALS AND FABRICATION

MODULE C: AIR DISTRIBUTION

UNIT I: DUCTING

HANDOUT 2: DUCT SYSTEM DESIGN

There are several techniques to consider in designing a good energy saving duct system. Sharp turns should be eliminated when possible in order to cut down on pressure losses that will occur when fast moving air is forced to turn a corner. Turning vanes should be installed inside elbows where sharp turns are necessary.

Ducts should be properly sized for the blower. If undersized, the air will move too fast through the ducts causing unwanted noise and excessive losses due to air friction along the duct walls. Long runs of ducts should be eliminated to avoid friction losses, also.

Location of the vents is also important. In a home where heating is the most important consideration due to long cold winters, warm air should enter the room near the floor so that the heat will rise by convection. The return air vents should be placed high on the walls and on opposite sides of the room. This allows the incoming warm air to rise from the floor and travel across the room.

Zoning of heating and cooling systems almost always provides the opportunity for lower energy consumption, since each zone can be maintained at the temperature required, without regard to the temperatures in other zones. Zoning also provides the owner with the opportunity to cut back on the heating and/or cooling to any rooms not being used. Tests have shown that zoning can achieve energy savings of 20% and more.

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COURSE VI: MATERIALS AND FABRICATION

MODULE C: AIR DISTRIBUTION

UNIT I: DUCTING

HANDOUT 3: DUCT INSULATION

The ducts used to heat and air condition a home can be a major source of energy loss. In the winter, heat energy is lost from the ducts into cooler, unheated spaces; in the summer, heat energy is absorbed by the air conditioning ducts passing through non-insulated spaces. Air conditioning ducts are also susceptible to water condensation, and this can rust out a duct system in just a few years.

In heating systems, a duct running through any unheated area, such as an attic, garage, or unheated crawl space, should be insulated to reduce heat loss. While special duct-wrapping insulations are available for this purpose, you might find it more economical to use regular batting insulation. Normally, two inches or more of insulation is needed to adequately insulate heating ducts. The insulation should have a protective covering or backing; although a vapor barrier is usually not required over the outside of the insulation if the duct is used only for heating. If the heating ducts run through an insulated crawl space, the ducts will not usually require insulation. In the winter, the crawl space should be high enough to prevent much heat loss through the exposed ducts.

Many new types of duct material are available. One type consists of fiberglass sheets that can be folded into a rectangle and taped in shape. The ends of each section are then notched and the pieces fitted together (like two pieces of pipe) and the seams are then taped to prevent air leakage. This fiberglass is manufactured with a vapor barrier covering (usually silver in color).

When air conditioning ducts run through any area that is not temperature controlled, the ducts must be insulated and covered with a vapor barrier. Exposed air conditioning ducts not only increase your cooling load, they also cause the warm surrounding air to condense water vapor on the ducts, and this encourages rusting and other moisture problems. During the cooling season, the crawl space is generally cool enough that no moisture will condense on the ducts. If you do have a condensation problem, a simple solution is to cut an outlet in the duct system to blow some cool air into the crawl space. This method normally results in an insignificant increase in your cooling load because the crawl space is sealed, insulated and fairly cool to begin with. Just install a vent in the duct outlet so that you can regulate the amount of cool air that enters the crawl space, and be sure to close the vent during the winter heating season.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE A: COLLECTORS

MODULE DESCRIPTION:

This module discusses the various types of active solar collectors. The components of the collectors are described in terms of materials and function.

The importance of the collector in a solar system is the primary concern of unit one of this module.

GOAL STATEMENT:

Since an understanding of the solar collector is basic in understanding solar energy in general, the collector will be studied in some detail.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE A: COLLECTORS

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- 2: Comparison of Collectors A-3
- 3: Swimming Pool Collectors A-5

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MODULE B: SOLAR STORAGE

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COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE A: COLLECTORS

UNIT I: INTRODUCTION

HANDOUT 1: BASIC PRINCIPLES

The most important component in a solar system which could improve performance is the solar collector. Improvements which will increase efficiency of energy collection and reduce the delivered costs are particularly worthwhile. Among many interesting possibilities are the addition of selective surfaces to absorbers, and collectors with the air evacuated from around the absorber plates to reduce heat losses and improve collector efficiency.

A solar collector is a means of intercepting incident solar radiation, converting this radiation to heat, and delivering useful energy to the system. A collector consists of an absorber plate, commonly a black metal surface, which absorbs the incident solar radiation and converts this solar energy to heat. A portion of this heat is transferred to a fluid and then transported to another part of the system. In the process of collecting energy and transferring the heat, the absorber plate will lose some of the heat to its surroundings, so other components of the solar collector are provided to reduce the heat losses.

Heat is lost from the absorber plate by radiation, convection, and conduction. Insulation beneath the absorber reduces the heat loss through the back of the collector, and the transparent covers reduce the heat losses from the "front" of the collector. A glass cover, which is opaque to the thermal radiation emitted by the plate, will reduce convection losses to the outside air because the air space between the absorber plate and cover restricts convective air motion.

The useful energy from a solar collector is transferred to a fluid and delivered directly to the building or to storage, where it can be used at a later time. The two principal types of fluid heating solar collects are liquid-heating solar collectors and air-heating solar collectors. Liquid heating collectors normally use water or a solution of water and ethylene glycol, antifreeze, but numerous other liquids can be used.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE A: COLLECTORS

UNIT I: INTRODUCTION

HANDOUT 2: COMPARISON OF COLLECTORS

A solar collector is a device used to collect solar radiation (energy) and to change it into usable heat. There are four types of collectors currently in use. The three most common types are flat-plate collectors, evacuated-tube collectors, and concentrating or tracking collectors.

Because of certain cost and performance advantages, the flat-plate collector is the workhorse of the solar energy industry. It has been used successfully for many years, on more solar energy systems than any other type of collector. Various designs of flat-plate collectors are currently manufactured by more than 175 companies.

In contrast, evacuated-tube collectors, photo-voltaic collectors and concentrating collectors have seen limited use. The necessary technology has just recently become economically feasible from a small number of manufacturers. For the most part, these collectors will not see the widespread application seen with flat-plate collectors.

The following sections will outline the operation and construction features of the three types of collectors:

Air collectors provide heated air at temperatures from 80°F to 180° or 200°F. With pumps not working, liquid temperatures may exceed boiling point of water or anti-freeze.

Air-heating solar collectors are less efficient than liquid collectors for the same inlet temperature, however, system efficiency is comparable. The air systems are not subject to overheating and corrosion but they do require larger ducting and storage components.

Flat-plate solar collectors absorb both direct and diffuse solar radiation. This is an important aspect of collectors, especially in areas where a large proportion of solar radiation is in the form of diffuse or reflected radiation. Flat plate collector's components are metal frame, glass cover or covers, absorber plate, piping or ducting, and bottom insulation. Typical size of collector is 3 ft. x 6 ft. x 7 in. Liquid-collector volumetric flow rate: typically 0.02 gpm per sq. ft. of collector area. Air collector flow rate: 2 cfm per sq. ft. of collector area.

Concentrating collectors produce higher output temperatures, but must track sun, and are useful only for direct radiation, not diffuse.

Evacuated tubes produce higher output temperatures, achieve higher efficiencies.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE A: COLLECTORS

UNIT I: INTRODUCTION

HANDOUT 3: SWIMMING POOL COLLECTORS

Perhaps the simplest method of heating swimming pools with solar energy is to cover the water surface with a large, thin, transparent (to solar radiation) plastic sheet. The cover will reduce heat loss due to evaporation, as well as heat losses by other forms and can be expected to increase the pool temperature by 12 to 20°F above mean ambient temperature (a summer average of about 15°F).

More conventional flat-plate collectors, available for heating swimming pools, usually consist only of a black plastic absorber. Usually these simple collectors do not utilize any transparent covers at all, since the plastic is not capable of withstanding the high temperatures that would be experienced under no flow conditions. While the fluid temperatures achieved by these collectors are low, they are adequate for swimming pool heating. The efficiency of a simple flat-plate collector is low, but the installed cost of the collector is also low, so that the cost-effectiveness, in terms of BTU per dollar, is reasonably high. Higher efficiencies can be achieved by using a copper absorber with high flow rate--all the swimming pool water through the panels. This allows the panels to operate cool. Efficiency is particularly high, since the normal transmission loss through the glazing is eliminated. Use of copper provides for excellent heat transfer.

Normally 2/3 the pool surface area is made up in solar panels, and this is increased if the panels lie at less than the recommended angle with the horizontal. Also, if the pool is shaded or if the wind is particularly strong, more panels will be needed. A roof parapet or screen erected around the plate area would assist the system by reducing the cooling effect of the wind.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE A: COLLECTORS

UNIT II: TYPES OF SOLAR COLLECTORS

UNIT OBJECTIVE

Upon completion of this unit the student will be able to describe the elements and the functions of the elements of various solar collectors.

SPECIFIC OBJECTIVES

Upon completion of this unit, the student will be able to:

1. Recognize the advantages and disadvantages of air-heating and liquid-heating collectors.
2. Identify and select the solar collectors best suited to meet specific requirements.
3. Describe methods of preventing corrosion and freezing.
4. Explain the factors contributing to solar collector durability.
5. Discuss the progress in photo voltaic cell development.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE A: COLLECTORS

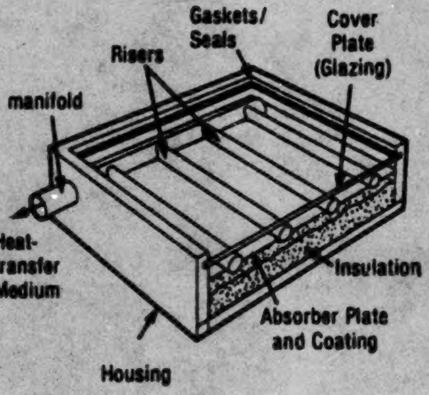
UNIT II: TYPES OF SOLAR COLLECTORS

HANDOUT 1: FLAT-PLATE COLLECTORS

The flat-plate collector has a simple construction and an easy-to-understand operation. It changes the sun's radiation into heat on a flat surface within a simple box. It can be permanently mounted on a roof or in a yard. It does not require special technology, reflecting surfaces, lens, or equipment for changing its angle in relation to the sun's position.

A typical flat-plate collector is shown in the illustration. There are seven major parts in a flat-plate collector. These are:

1. a cover plate or glazing
2. an absorber plate coating
3. an absorber plate
4. gaskets or seals
5. insulation
6. a collector box or housing
7. passages for heat-transfer medium


Gaskets/
Seals
Cover
Plate
(Glazing)
Risers
manifold
Heat-
transfer
Medium
Insulation
Absorber Plate
and Coating
Housing

The glazing plate is a transparent sheet of glass or plastic that is mounted above the absorber plate. It provides an air space in the collector. The sun's rays can penetrate the glass and be transformed into heat energy on the absorber plate. The cover plate then prevents this heat energy from escaping through the front of the collector. Some designs use double or triple covers for added protection against heat loss.

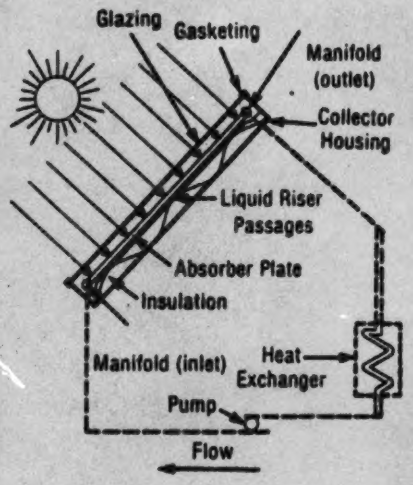
The absorber plate collects the heat energy which is transmitted through the cover plate. It has a black absorptive coating to improve its ability to absorb energy without reflecting it away. It also has passages in which the heat-transfer medium (air or fluid) can flow and carry off the heat to storage. These passages include headers and risers. The headers are main passages or manifolds through which the heat-transfer medium enters or exits the collector. They are located at the top and bottom of the collector, or on both sides. The risers are pipes that carry the heat-transfer medium across the face of the collector. They are connected to the headers, evenly spaced from one end to the other.

Insulation is packed behind the absorber plate and around the outer edges of the absorber plate. This insulation protects against heat loss through the back and sides of the collector.

All of the components of a flat-plate collector are firmly mounted in a weathertight box. This collector housing prevents moisture, dirt, dust, and air from entering the collector and affecting its performance. Rubber seals or gaskets are used to fasten the cover glazing on the housing. These seal out contaminants, but allow the cover to be easily removed if collector repairs are needed.

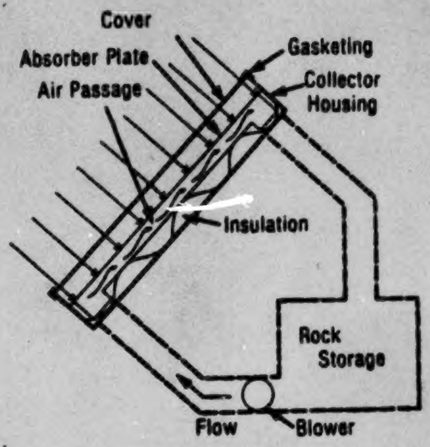
Flat-plate collectors are classified according to the type of heat-transfer medium they use. Liquid-type collectors use a liquid as the heat-transfer medium. This liquid might be water, silicone fluid, or one of several other fluids. Air-type collectors use air as the heat-transfer medium.

A cross-sectional view of a liquid-type flat-plate collector is shown in the illustration. The basic components of the collector and the collector loop are highlighted. This type of collector is used most often on solar systems that provide both water heating and space heating. Compared to air-type collectors, a liquid-type offers advantages in heat storage and heat delivery for new construction as well as existing buildings.


Glazing
Gasketing
Manifold (outlet)
Collector Housing
Liquid Riser Passages
Absorber Plate
Insulation
Manifold (inlet)
Heat Exchanger
Pump
Flow

The operation of a liquid-type flat-plate collector is very simple. Solar radiation passes through the cover glazing and strikes the absorber plate. The coating on the plate helps to absorb the radiation and turn it into usable heat. This heat, in turn, is absorbed by the heat-transfer medium in the plate's fluid passages. A pump in the collector loop circulates the heated fluid to a heat exchanger. This heat exchanger is part of a secondary pumping loop which removes the heat energy from the fluid and places it into a space-heating liquid storage tank or a water preheater tank. Then the heated fluid can be pumped away from the collector and replaced with cooler fluid.

A cross-sectional view of an air-type flat-plate collector is shown in the illustration. The basic components of the collector and the collector loop are highlighted. This type of collector is most commonly used on solar systems that provide only space heating and cooling. Its use for water heating is limited.



The operation of the air-type flat-plate collector is similar to that for the liquid-type flat-plate collector. However, air has a much lower heat capacity than water or any of the other heat-transfer liquids. About 3500 cubic feet of air are needed to transport the same amount of heat as one cubic foot of water. As a result, the air-type collector is usually much larger than a liquid-type collector of comparable capacity. The absorber plates are larger. Thin or narrow fluid passages are replaced with much thicker air ducts. The underside of the absorber-plate is usually roughened and made with fins or other such baffles to promote turbulence in the heat-transfer air. The air will not efficiently transfer heat from the absorber plate if it flows in smooth layers under the plate.

With air-type flat-plate collectors, the pump in the collector loop is replaced by a blower. And the liquid storage tank is replaced by a much larger rock-pebble storage bed. A heat exchanger is not used between the collector loop and and storage.

The design and performance of both types of flat-plate collectors is well known. Unlike other types of collectors, both collect all three types of solar radiation--direct, diffuse, and reflected. They are especially efficient at lower collection temperatures for water heating and space heating. They are not as efficient as some other collectors at the higher collection temperatures needed for space cooling.

Properly engineered and installed, the flat-plate collector is reliable, safe, and durable with known performance parameters. Designs do vary from manufacturer to manufacturer, however. The design and materials of construction can have an effect on collector performance. Later sections detail the different materials used and show you how various collector designs can be compared for efficiency. The illustration lists some of the materials usable for collector components.

COLLECTOR COMPONENT	MATERIALS USED
Cover Plate or Glazing	Glass, fiberglass laminates, thermoplastic sheeting and film
Absorber Plate Coating	Selective metal oxides, nonselective black paints
Absorber Plate	Copper, aluminum, stainless or carbon steel
Fluid Passages	Aluminum or copper tubes, integral spaces in absorber plate
Insulation	Fiberglass, glass foam, foamed thermoplastics
Housing	Metal, honeycombed concrete, fiberglass laminates, extruded thermoplastics
Gasketing	Silicone, EPDM, butyl, PVC elastomers
Heat-Transfer Medium	Air, water, silicone fluid, hydrocarbon oils water/glycol mixtures

The flat plate collector is designed to deliver energy at temperatures up to approximately 150°F ambient temperatures. Its top operating temperatures under flow conditions are in the area of 150° to 240°F. It collects direct, diffuse, and reflected radiation. It does not need to be oriented directly toward the sun at all times of the day, and it requires minimal maintenance over its lifetime. Properly designed and engineered, flat-plate collectors have a life expectancy of 20 to 25 years, perhaps longer depending on the design. The cost of energy delivered from a flat-plate collector depends on its thermal performance, its installed cost, and its effective life.

The performance of flat-plate collectors is well known and predictable. Collector efficiency is usually measured as a ratio of the useful energy collected to the incident energy striking the collector cover. As a formula:

$$\frac{\text{Energy Collected}}{\text{Energy Available}} \times 100 = \%\ \text{Collector Efficiency}$$

Major factors affecting the efficiency of a flat-plate collector are:

The rate at which heat is removed from the collector. This is labeled "F_R".

The heat losses from the collector. This is labeled "U_L".

The amount of energy transmitted through the cover and absorbed by the absorber plate. This is labeled "$\tau\alpha$".

When these factors are known, the collector performance can be predicted with accuracy. They are usually set and controlled by the design of four major collector parts:

1. The transparent covers.
2. The absorber plate coating.
3. The absorber plate design.
4. The collector insulation.

COURSE VII: COLLECTORS AND ENERGY STORAGE

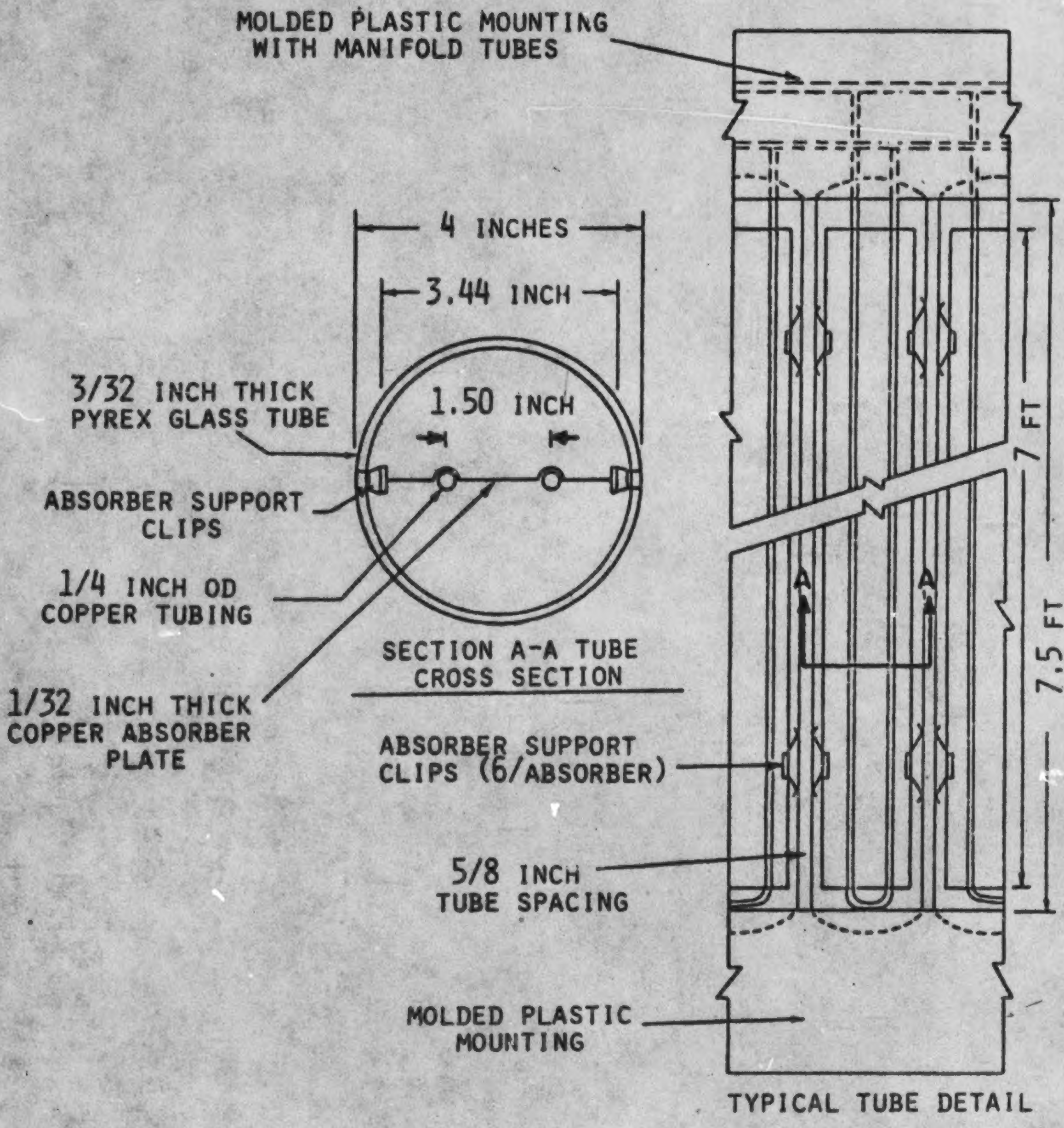
MODULE A: COLLECTORS

UNIT II: TYPES OF SOLAR COLLECTORS

HANDOUT 2: EVACUATED-TUBE COLLECTORS

Evacuation of the air around the absorber plate is potentially a significant improvement in solar collectors. There are a number of different designs that are being assembled and tested, and at least one manufacturer makes them in moderate quantities. Evacuated collectors will produce more useful heat than standard flat-plate collectors under equal sun and weather conditions because the losses from the absorber are greatly reduced. With a vacuum surrounding the absorber, conduction and convection losses are effectively negligible and, if the absorber coating is a selective surface, the radiation loss is small.

One design, by Corning Glass Works, is shown on the following page. Inside an evacuated glass tube which is four inches in diameter is a copper absorber plate with a selective surface. Bonded to the plate is a copper U-tube which carries the heat transfer fluid. The ends of the tube protrude through one end of the glass tube, and the absorber plate is free to expand toward the other end. The efficiency

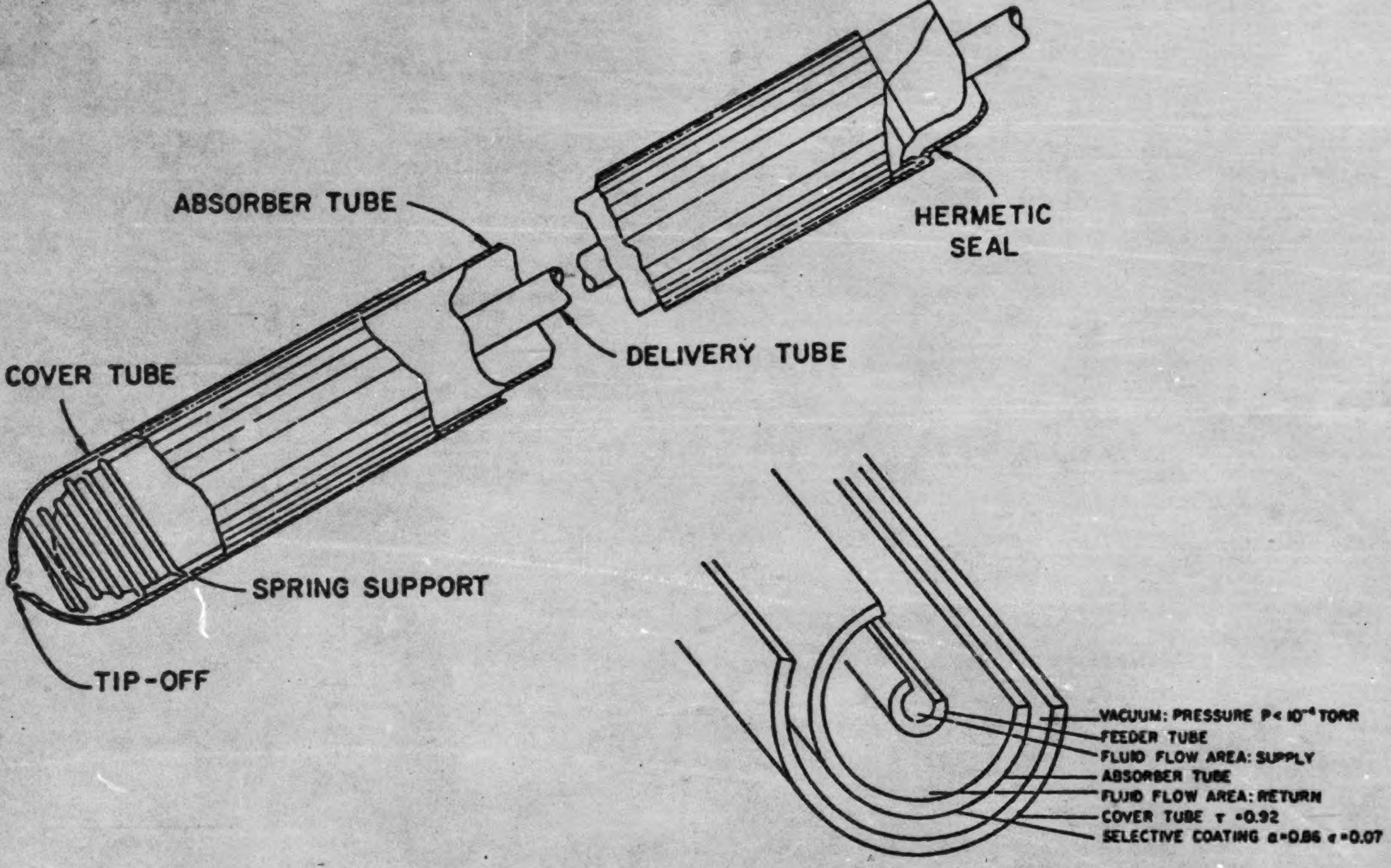

MOLDED PLASTIC MOUNTING WITH MANIFOLD TUBES
4 INCHES
3.44 INCH
1.50 INCH
3/32 INCH THICK PYREX GLASS TUBE
ABSORBER SUPPORT CLIPS
1/4 INCH OD COPPER TUBING
1/32 INCH THICK COPPER ABSORBER PLATE
SECTION A-A TUBE CROSS SECTION
A
A
7 FT
7.5 FT
ABSORBER SUPPORT CLIPS (6/ABSORBER)
5/8 INCH TUBE SPACING
MOLDED PLASTIC MOUNTING
TYPICAL TUBE DETAIL

Corning Glass Company Evacuated Tube Collector

range of the collector varies from about 74 percent when the inlet fluid temperature is low to about 60 percent when the fluid is near the boiling temperature of water. Most flat-plate collectors have high efficiency with low inlet fluid temperatures, but have low efficiencies when the fluid temperature is near boiling. The evacuated tube collector has a significant advantage when producing high temperature heat to the system and can be used effectively with solar cooling units where high temperature fluid is needed.

An evacuated tube collector design by the Owens-Illinois Glass Company is shown on the following page. There are three concentric glass tubes with the middle one coated with a black selective surface. The vacuum is between the outer and middle tubes. Fluid is transported through the inner tube and, as it passes through the annulus in contact with the absorber tube, heat is transferred from the glass to the fluid.

Two other evacuated tube collectors are being experimentally tested, one by the General Electric Company for use in air-heating systems and another is by the Philips Company in West Germany for liquid systems. Many variations in design of evacuated tube collectors are possible, and different designs will gradually advance to the practical stage.


ABSORBER TUBE
HERMETIC SEAL
DELIVERY TUBE
COVER TUBE
SPRING SUPPORT
TIP-OFF
VACUUM: PRESSURE $P < 10^{-4}$ TORR
FEEDER TUBE
FLUID FLOW AREA: SUPPLY
ABSORBER TUBE
FLUID FLOW AREA: RETURN
COVER TUBE $\tau = 0.92$
SELECTIVE COATING $\alpha = 0.86$ $\epsilon = 0.07$

Schematic of the Owens-Illinois Evacuated Tube Solar Collector

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE A: COLLECTORS

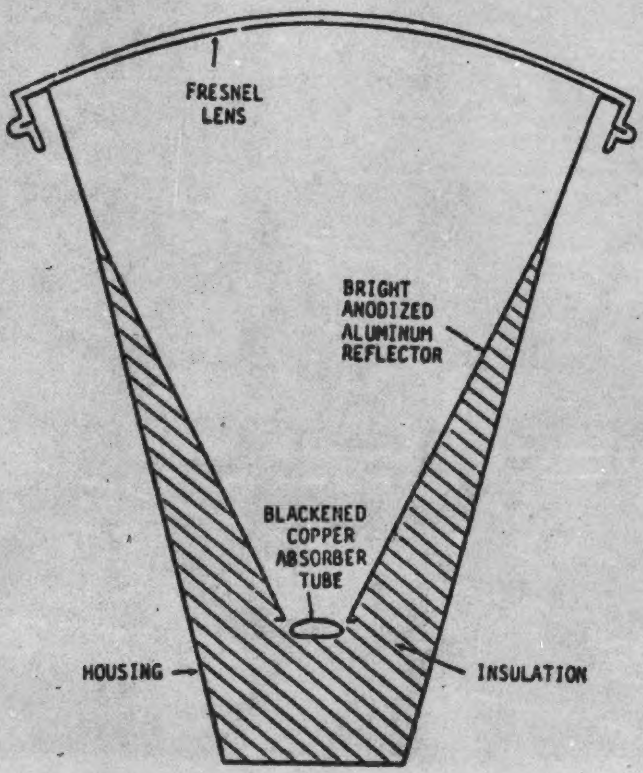
UNIT II: TYPES OF SOLAR COLLECTORS

HANDOUT 3: CONCENTRATING COLLECTORS

Concentrating collectors are sometimes called focusing collectors or tracking collectors. The sun's radiation is reflected off one or more mirrors to concentrate it onto a very small absorber area. Most concentrating collectors require mechanical devices to shift the collector position and track the sun in its travel across the sky. Some require special optical lens arrangements to help focus the sun's energy.

Concentrating collectors are used when very high temperature fluid is needed to drive heat engines or to be used in industrial processes. If concentrating collectors can be designed to be more efficient than flat-plate collectors, operate reliably, and with little maintenance so that the cost of delivering energy is low, then such collectors can have potential uses in residential solar systems. Experience thus far has indicated otherwise, but there is considerable research under way and new designs for concentrating collectors are being developed.

One type of low concentration collector is being developed by the Northrup Company and is being tested on a number of solar systems for large buildings. A linear focusing collector with a Fresnel lens is the type being developed and is shown below. The collector is mounted with the axis on the north-south direction and tilted at an angle with respect to the horizontal plane. The collector rotates from east to west during the day so that the direct rays from the sun are focused into the absorber tube. A distinct disadvantage of concentrating collectors is that only the direct rays from the sun are used, as the diffuse radiation cannot be focused.


FRESNEL LENS
BRIGHT ANODIZED ALUMINUM REFLECTOR
BLACKENED COPPER ABSORBER TUBE
HOUSING
INSULATION

Fresnel Lens Strip Solar Collector

MODULE A: COLLECTORS

UNIT II: TYPES OF SOLAR COLLECTORS

HANDOUT 4: PHOTO-VOLTAIC CELLS

Photo-voltaic cells are special solar collectors that change the sun's energy directly into electricity. The photovoltaic cell consists of an np junction between two different semiconductors, an n-type material in which conduction is due to electrons, and a p-type material in which conduction is due to positive holes. When light is absorbed near such a junction, new mobile electrons and holes are released causing a small electrical field at the junction, resulting in electrical energy. The current produced by short-circuiting solar cells is directly proportional to light intensity and in direct sunlight is about 28 milli-amps per square centimeter. A maximum output power of about 11 milliwatts per cm^2 at an output of .45 volts. The top efficiency of these cells is around 11%.

Typical junctions for photo-voltaic cells are:

1. Silicon - silicon boride
2. Selenium - iron
3. Copper oxide - copper

Three recent reports, one commissioned by the Federal Energy Administration, and others by Congress' Office of Technology Assessment and the President's Council on Environmental Quality, suggest major and imminent reductions in the cost of manufacturing solar electric, or photo-voltaic, cells. FEA's report is especially optimistic about the impact of simple mass production technology on the costs of well-known, single crystal, electric cells.

In 1976, 300 to 350 kilowatts of solar cells were sold at the high price of $12,000 per kilowatt. For remote power production, where transmission lines are expensive to acquire and end-use needs are not great, photo-voltaics can be economic today.

An FEA report, written by the BDM Corporation of McLean, Virginia, concludes that a cost effective purchase by the Department of Defense for 153 megawatts of remotely sited solar electric cells could bring production costs down to a level competitive with nuclear power, or better, inside of six years. Obviously such conclusions have serious implications for power companies planning expansion programs, and the report has not benefitted from wide distribution.

Silicon does not need to be as pure for solar cells as is necessary for semiconductors. Therefore, the Federal Government has made available large sums of money for the

development of a less expensive solar cell. The price of solar-cell electricity has been dropping very rapidly and should become competitive in the very near future. It is now competitive in low-electrical-demand, remote areas.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE A: COLLECTORS

UNIT III: COMPONENTS OF COLLECTORS

UNIT OBJECTIVES

Upon completion of this unit the student will be able to identify and describe the functions of the individual components of a variety of solar collectors.

SPECIFIC OBJECTIVES

Upon completion of this unit, the student will be able to:

1. Describe the function of various fluids in collectors.
2. Discuss the various types of glazing.
3. Discuss the various types of absorbers.
4. Recognize the various types of insulation and housing.

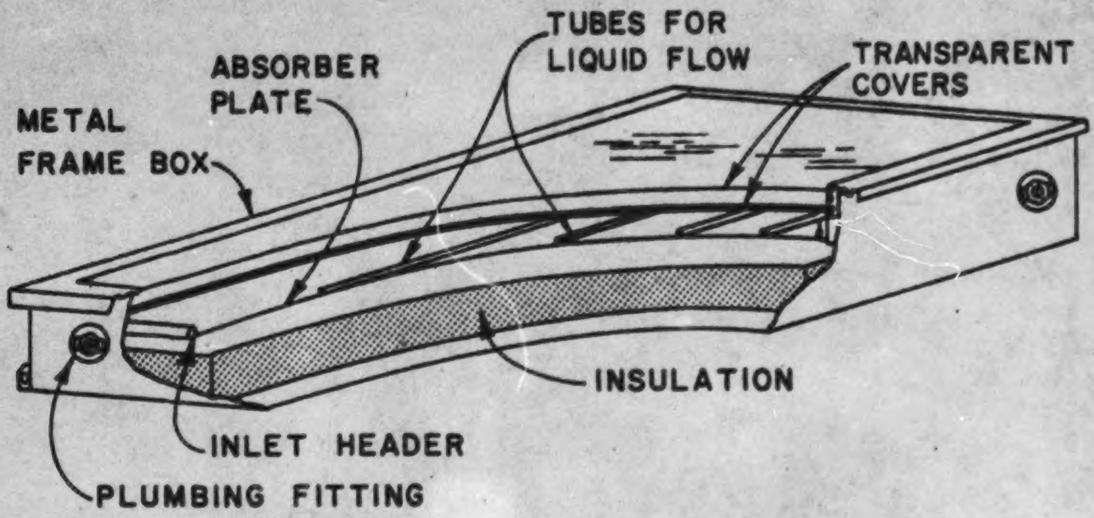
COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE A: COLLECTORS

UNIT III: COMPONENTS OF COLLECTORS

HANDOUT 1: COVERS (GLAZINGS)

The physical and optical stability of thin transparent plastic films and sheets under ultraviolet radiation and also at the high temperatures that are developed in solar collectors is not well established. Tedlar and polycarbonate sheets have been used, but glass is commonly used for solar collectors.


TUBES FOR LIQUID FLOW
ABSORBER PLATE
TRANSPARENT COVERS
METAL FRAME BOX
INSULATION
INLET HEADER
PLUMBING FITTING

Solar Collector

The optimum number of glass covers depends on collector design, the fluid temperature desired, and the outdoor air temperature. For flat-plate collectors in systems that are used only for winter heating, one glass cover is suitable where average winter air temperature is greater than about 45°F. Two glass covers should be used for collectors in colder climates.

While there is some questions of glass breakage from wind and hail storms, use of tempered glass and small collector widths will reduce risks of glass breakage.

The following table shows a comparison of various materials used for collector glazings.

Glazing Type	Solar (Shortwave) Transmittance, Percent	Infrared (Longwave) Transmittance, Percent	Index Of Refraction	Weatherability And Durability
White Crystal Glass	91.5	2	1.50	Excellent
Low-Iron Tempered Glass	87.5	2	1.51	Excellent
Low-Iron Sheet Glass	87.5	2	1.51	Excellent
Tempered Float Glass	84.3	2	1.52	Excellent
Fiberglass	77 to 87	0.1 to 0.3	1.54	Fair to Good
Sheet Acrylic	80 to 90	2	1.49	Average to Good
Sheet Polycarbonate	73 to 84	2	1.59	Poor to Fair
FEP Teflon	90 to 92	25 to 26	1.34	Fair to Good
Polyester Film	80 to 87	20 to 21	1.64 to 1.67	Fair to Good

The physical and mechanical properties, as well as the cost, must be taken into consideration in making a choice. Tensile, tear, burst, flexual, and impact strengths need to be adequate. The cost per square foot has an important impact on initial installed cost. Vinyls are inexpensive, but they can only be used as external glazing and only when there is a second layer of glass or teflon beneath. Vinyls have low deformation temperatures. Teflon is excellent as an interior covering, but it is as expensive as glass and too thin for outer covering. Teflon also has a high transmittance of infrared. Fiberglass reinforced polyesters make fair glazing. They are relatively inexpensive and easy to work with.

The energy striking the surface of the glazing must be absorbed by the surface, reflected, or transmitted through. Whether the energy is absorbed, reflected, or transmitted depends on: wavelength; angle of incidence; glazing's refractive index, a relative measure of how much the surface will bend the energy beams as they pass through the material; and glazing's absorptive index, a relative measure of how much energy the surface will absorb.

An effective glazing must transmit the maximum amount of the sun's energy. It must transmit that energy at all angles of incidence. And it must not bend that energy so that it cannot strike the absorber plate.

But an effective collector glazing must also reflect the maximum amount of heat energy which might be given off by the absorber plate. Since this heat energy usually has a different wavelength than the sun's radiation, this can be accomplished with the same material that might transmit the sun's energy.

An effective collector glazing must not present a reflective surface or one that would absorb a large amount of energy. Energy reflected off the outside of the glazing is lost for collection purposes. The same is true for energy absorbed by the glazing. However, absorbed energy will increase the glazing temperature. This helps somewhat in maintaining temperatures inside the collector.

The sun gives off shortwave radiation, with energy at wavelengths of .1 to 4.0 micrometers. The heat energy given off by the absorber plate inside the collector is longwave radiation, with wavelengths greater than 3.0 micrometers.

The best collector glazings would have the following characteristics:

1. High shortwave transmittance
2. Low longwave transmittance
3. Low absorptance at all wavelengths.
4. Excellent weatherability and durability

Some swimming pool water-heaters do not have a glazing. The water is pumped through at a high rate. This allows the absorber to operate cool, thereby eliminating the need for a glazed box. This type of collector is satisfactory for low temperature water and where the exposed absorber is not struck by a lot of wind.

Warmer climates use single-glazed collectors for space and domestic hot water up to around 150°F. If your hot water needs are only 120°F, a single-glazed collector should be considered even in colder climates.

Colder climates use double-glazed collectors for space and domestic hot water up to around 160°F. If you need very hot water in warmer climates, a double-glazed collector should be used.

In very cold climates or for very hot water in warmer climates, a triple-glazed collector should be considered, but the efficiency will be low. It would seem that if two layers are better than one, 3 layers would be better still. Wrong. One layer of good glazing transmits about 92% of the radiation that hits it to the collector plate, but 2 layers only let through about 80%. After that, the law of diminishing returns takes over again.

For glazing spacing, there should be about 1/2 inch of space between layers of glazing and at least 3/4 of an inch to 1 inch of space between the inner glazing and the absorber plate.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE A: COLLECTORS

UNIT III: COMPONENTS OF COLLECTORS

HANDOUT 2: ABSORBERS

The absorber plate in a collector is the portion which gathers the energy transmitted through the cover. It must be efficient in absorbing and holding that energy. And it must be constructed in such a way that the energy can be efficiently removed by the heat-transfer medium. The absorber plate coating and the flow configuration on the plate are extremely important for an efficient collector.

A surface coating is placed on the absorber plate to improve its ability to collect and hold energy. Two types of coatings are used. These are selective surfaces and nonselective surfaces. Selective surfaces will collect most of the sunlight hitting them and will emit very little thermal radiation. Nonselective surfaces will also collect most of the sunlight, but they will emit a high level of thermal radiation.

Selective surfaces are usually defined in terms of energy wavelengths. The surface will absorb a very high amount of shortwave solar energy. And it will emit a very low amount of longwave heat energy.

ABSORBER PLATE

Metal is the best material for absorber plates. In liquid-heating collectors, the tubes must be thermally bonded to the absorber plates to conduct the heat from the plate to the tube wall. The thermal contact between the tube and the absorber plate is satisfactory with tube-in-sheet absorber plates. Other absorber plate configurations include:

1. Tube in strip
2. Tube in panel
3. Tube on strip
4. Tube on panel
5. Waffled panel
6. Fin on tube
7. Finned tubing

A major difficulty in the use of aluminum is the possibility of corrosion of the tube walls. While corrosion can be effectively limited by additives in the heat transfer fluid, it is not totally inhibited. Copper or steel absorber plates are also used quite extensively, but copper tubes are expensive and steel plates are heavy. Some absorber plates consist of copper tubes bonded to a less expensive metal plate.

The pressure drop through the tubes of an absorber plate is a function of the flow rate through the tubes. The flow rate is selected on the basis of a desired temperature increase in the heat transfer liquid from the inlet to the outlet. The flow rate will vary with the temperature in the fluid because the viscosity of the liquid varies with temperature. A temperature rise across the collector of about 14°F with peak insolation is a reasonable design basis. The flow rate through the tube to achieve the temperature rise is about 0.02 to 0.03 gallons per minute for each square foot of collector. It is important to achieve a finite pressure drop along the tubes attached to the absorber plate to assure satisfactory flow distribution among all the tubes.

It has been experimentally determined that satisfactory flow distribution in a solar collector is achieved when the head loss along one header is less than one-tenth of the total head loss from inlet to outlet. Likewise, when solar collector arrays are arranged, it is important that the flows be equal through all the collectors.

BLACK PAINT ABSORBER COATING

There are many types of paints to coat absorber surfaces. An acceptable black absorber coating, suitable for air and liquid collectors is a 3M brand Nextel Black Velvet Coating. A Nextel primer is recommended before the coating is applied. One gallon of the paint covers about 200 square feet of absorber surface area. The solar reflectance of this coating is less than two percent. Because all paints contain some amount of binders, the painted surfaces should be heat treated at about 300°F for about 3 hours. Pre-heating will prevent off-gassing from the absorber coating and condensation of volatile components on the lower cover glass. The condensation of paint binders on the lower glass cover reduces the transmission of solar radiation through the glass.

Black paints are inexpensive and relatively easy to apply, but there are some disadvantages. While there is high absorptivity of the solar radiation with a black paint, there is also high emissivity. High emissivity results in high radiation heat loss from the absorber. There are special black selective surface materials which result in high absorptance of solar radiation and low emittance of thermal radiation. Selective surfaces convert a large fraction of solar radiation to heat and supress radiation heat loss so that more useful heat is delivered from the collector when compared to one with a black painted surface. Various selective surfaces are being developed by amny collector manufacturers and in the next few years they will be in common use for flat-plate collectors.

SELECTIVE SURFACES

Most surfaces that are good absorbers for solar radiation are also good radiators of heat. If a surface has an absorptivity of 0.95 for solar radiation, it will normally radiate heat at a rate of about 95 percent of that of a "perfect" radiator. Certain combinations of surfaces, however, are capable of absorbing solar radiation effectively, while at the same time radiating heat at a low rate. These combinations are known as selective surfaces. Most selective surfaces are made up of a very thin black metallic oxide on a bright metal base. The black oxide coating is thick enough to act as an effective solar absorber, with an absorptivity as high as 0.94, but it is essentially transparent to long-wave thermal radiation emitted by an object at a temperature of several hundred degrees F. Since bright metals have low emissivity for thermal radiation and since the thin oxide coating is transparent to such radiation, the combination is a poor heat radiator. As a result, the radiation loss from this type of surface is considerably lower than from a conventional, non-selective surface. Thus, the overall heat loss coefficient, U_L, has a lower value when this type of surface is used.

A most successful and stable selective surface developed to date is made by electroplating a layer of nickel on the absorber plate, then electro-depositing an extremely thin layer of chromium oxide on the nickel substrate. Nickel oxide coatings have also been used, but they are less resistant to damage from moisture. Coatings of copper oxide on bright copper and nickel have similar properties, but temperature stability is limited. The most effective selective surfaces have solar absorptivities near 0.95 and thermal emissivities near 0.1.

HANDOUT 3: INSULATION AND HOUSING

INSULATION

The back and sides of the collector must be insulated for maximum collector efficiency. The back losses are a function of the thermal conductivity of the insulation and its thickness. The ambient temperature at the back of the collector is normally much lower than at the glazing. The back is shaded and is receiving no solar radiation. In a well-designed collector using edge insulation equivalent in R-value to that on the back, the losses are small.

Insulation in a good flat-plate collector should have:

1. No outgassing or fuming at a temperature of 400°F.
2. An R-value of at least 10.
3. A resistance to water.
4. A resistance to compacting.

Insulating materials that meet the above qualifications and could be considered for use are: fiberglass, ceramic fiber, mineral fiber, foamed glass and thermoplastics. Do not use fiberglass with phenolic binders. The phenolic compounds will probably outgas at stagnation temperatures.

COLLECTOR HOUSING

The functions of the collector housing are to:

1. Provide a weathertight enclosure for the absorber plate and the insulation.
2. Provide a stable mounting of the collector module to the supporting structure.
3. Provide a support for a weathertight and secure cover glazing.

The most common types of collector housings are made of:

1. Aluminum
2. Galvanized sheet metal
3. Fiberglass laminates
4. High-temperature thermoplastics
5. Wood
6. Honeycombed lightweight agregate concrete shells

The normal trouble spots in the collector housing are met whenever assembly takes place. This primarily involves securing the back to the sides and the cover to the sides. Remember, particularly with metals, that gross expansion and contraction takes place during thermal cycling. This must be allowed for in the design.

The most troublesome part of the collector is the interface between the cover glazing and the collector box. Usually, the collector box has a different rate of thermal expansion than the covering. If the seals fail, moisture will enter the collector. The covering will fog and the insulation may slump.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE A: COLLECTORS

UNIT IV: EFFICIENCY

UNIT OBJECTIVES

Upon completion of this unit the student will be able to identify and discuss the parameters which affect collector efficiency.

SPECIFIC OBJECTIVES

Upon completion of this unit, the student will be able to:

1. Define collector efficiency.
2. Recognize effect of system design changes on collector performance.
3. Compare the performance between various collectors.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE A: COLLECTORS

UNIT IV: EFFICIENCY

HANDOUT 1: SOLAR COLLECTOR EFFICIENCY

STEADY-STATE COLLECTOR EFFICIENCY

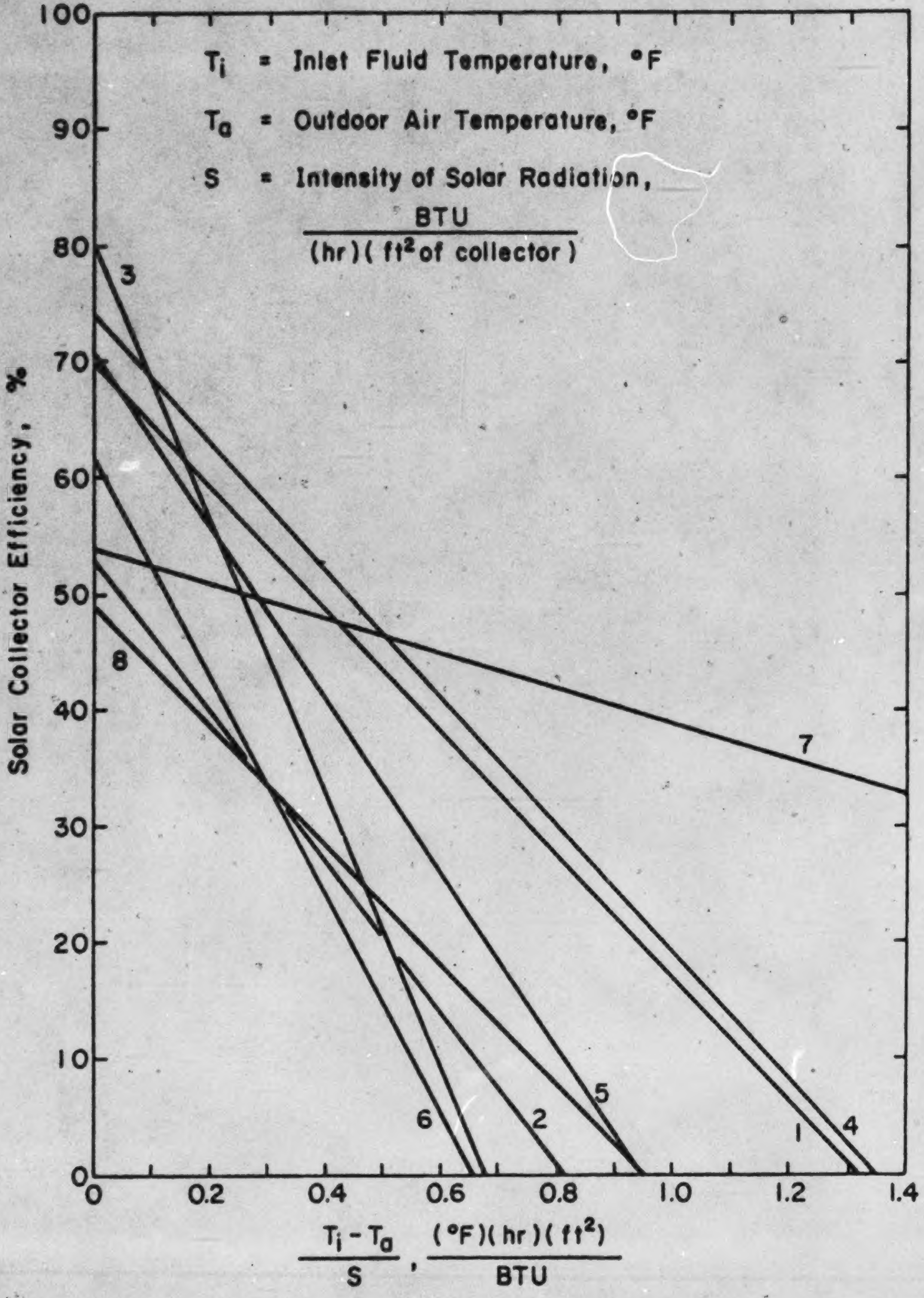
Solar collector efficiency is the fraction of the solar energy intercepted by the collector that is converted to heat and delivered to the building. Factors which influence solar collector efficiency include absorber surface coating, number and type of transparent covers, fluid flow distribution through the collector, fluid temperature, outdoor air temperature, and the intensity of solar radiation on the collector glass area.

The efficiencies of solar collectors are usually expressed as a function of inlet fluid temperature and ambient air temperatures. While use of inlet fluid temperature in the efficiency curves presented by manufacturers is acceptable for liquid heating collectors, it is not a useful variable to express the efficiency changes for air-heating collectors. This is because the inlet temperature to an air-heating collector in a system is always near room temperature, while the inlet fluid temperature for a liquid-heating collector varies considerably during the day. The comparison of liquid-heating collectors can be based on efficiency curves similar to those on the following page.

Curve	Abs Mat	Source	Absorber Surface Coating	Transparent Covers Number	Transparent Covers Material	Stagnation Temperature °F
1	Al	NASA	black nickel	2	glass	466
2	Al	MSFC	black nickel	2	Tedlar	313
3	Al	NASA	black paint	1	glass	274
4	Al	NASA	black paint Mylar Honeycomb	2	glass	475
5	Al	NASA	black paint	2	glass	355
6	Al	PPG	black paint	2	glass	268
7	Glass	Evac tube	selective	1	glass	1150
8	Steel	Solaron air	black paint	2	glass	355

The preceeding table was determined with an incident solar radiation of 300 BTU/ft^2/hour and an ambient temperature of 70°F.

Comparisons of liquid and air-heating collectors are difficult. Unfortunately, no easy method has been determined to compare the performance characteristics of air and liquid-heating collectors, but a recent study of two similarly sized systems on comparable houses at the same location and during the same time periods shows that the air-heating system collected more useful energy than did the liquid system. One



Solar Collector Efficiency

is cautioned, however, that more data are needed before definitive conclusions about collector and system performance can be made.

The efficiency of an air-heating solar collector increases with air flow rate, but large air flow rates require large blowers and large electricity consumption in proportion to the solar energy collected. A recommended air flow rate for air collectors is about 2 cfm per square foot of collector.

For liquid-heating solar collectors, the liquid flow rate should be between 0.6 and 1.2 gallons per hour per square foot of solar collector area. Only a small gain in energy collection, hence collector efficiency, is realized by circulating more than 1.2 gal/(hr)(ft^2). On the other hand, when less than 0.6 gal/(hr)(ft^2) is circulated, the efficiency is significantly reduced.

DAILY COLLECTOR EFFICIENCY

The efficiencies shown on the Solar Collector Efficiency Graph are not appropriate for long-term collector efficiency, such as daily efficiency, because the fluid and ambient temperatures as well as the solar radiation continuously change during the day. The efficiencies shown on the graph are for steady-state conditions and, while they are useful for comparing different collectors (one fluid type), they are not directly useful to determine the quantity of energy collected by a system during the day. An average daily efficiency of collectors in a system is more useful for that purpose.

During the year the average daily efficiency varies from 15 to 25 percent, depending on the solar and climatic conditions and the operation of the system. The higher temperatures of storage water required for operating the cooling system during the summer lowered the collector efficiency when compared to winter conditions.

While average daily collector efficiency is dependent upon many design factors of the system, a daily efficiency from 25 to 35 percent can be expected with most collectors now available commercially. Because the collector is a very important component of a solar system, and the performance of the entire solar system is the important factor in system economics, individuals are discouraged from making their own collector unless the person has considerable experience and knowledge about solar collectors.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE B: SOLAR STORAGE

MODULE DESCRIPTION:

Energy storage is necessary for solar heating, cooling, and service hot water heating installations. The main purpose of thermal storage in a solar heating and cooling system is to provide heat overnight and over cloudy periods during the day. The heat must be easily stored from the collectors, readily supplied to the heating and cooling system, have few internal losses or losses to the environment, be inexpensive and not take an excessive floor space area. There are limitations to storage size for a given collector area. Several factors, the most important of which is cost, dictate that storage should be designed to serve from one to two days.

GOAL STATEMENT:

Since all solar heating systems depend on the storing of solar energy within a material for a period of time and solar cooling systems do the opposite, a knowledge of solar storage is essential to the proper design and understanding of all solar systems.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE B: SOLAR STORAGE

UNIT I: INTRODUCTION

HANDOUT 1: TYPES OF STORAGE

The two principal types of storage, water storage and rock bed storage, are in common use today. Both types are based on sensible heat storage, in which the quantity of heat stored is directly proportional to the temperature rise in the storage medium. Storage of heat in water is normally used with a hydronic system and storage in a rock bed is normally used with a hot air system. Water has a high capacity for heat storage and, although rocks have one-fifth as much as water, both rocks and water are inexpensive.

Another heat storage possibility is the use of phase change materials like eutectic salts. These materials store latent as well as sensible heat. That is, they utilize the heat of liquefaction as the primary means of storing heat. Large amounts of heat can be stored and released by the process of melting and solidifying without change in temperature. One advantage in the use of these materials is that smaller storage size is needed as compared with a water tank or a rock bed. However, there are a number of problems that are associated with these materials that have been examined by researchers for years and have not as yet been resolved. Heat may be stored for use in heating and cooling residential buildings in the forms of latent heat, sensible heat, and the combination of latent and sensible heats.

Latent heat can be stored by melting a solid, such as wax, into a liquid. The stored heat is released when the temperature drops and the heat which is released is supplied to the conditioned space. If a suitable material is used, solar heat at temperatures provided by collectors can be used to melt a solid and to store the heat during the day, then be made to release the heat when the liquid changes back to a solid form. Only a small temperature difference is enough to alter the phase from solid to liquid or liquid to solid. The use of ice to cool an "ice box" and to cool liquids is an example of the use of latent heat for cooling.

There are also two principal advantages to latent heat storage. As very large quantities of heat can be stored and released per pound of material, it takes much less volume to store the heat required by the system. A latent heat storage unit using wax would require about one-fourth as much volume as a water tank to store an equivalent amount of heat. A second advantage is that the temperature remains nearly constant during phase changes. A steady operating temperature for hot storage or cold storage is particularly advantageous for operating a chiller.

However, there are some disadvantages with latent heat storage units. Many known latent heat materials will last only a few years then must be replaced. Suitable materials are costly when compared to water or pebble-bed storage units. More time is needed for development of practical latent heat storage units.

Sensible heat is stored when the temperature of a storage medium increases. Water and pebbles are the common materials used for sensible heat storage because they are low in cost and readily available. Any thermally and chemically stable solid or liquid may be used if the costs are justifiable.

The amount of heat required to raise the temperature of one pound of matter one degree is the heat capacity of the material. Water has three times the heat capacity as compared to rock for the same volume. This means that a pebble-bed storage unit would be three times larger than a water tank to store the same amount of heat.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE B: SOLAR STORAGE

UNIT I: INTRODUCTION

HANDOUT 2: STORAGE LOCATION, SIZE AND HEAT LOSS

LOCATION

Solar heat storage units may be located above or below grade and either inside the heated building or outside. It is advised that the storage unit be placed within the building enclosure whenever possible and close to other solar equipment. An inside storage location has the advantage in that it is protected from moisture and cold, and the heat loss from the storage unit will aid in heating the building in winter. The disadvantages of locating the heat storage unit inside are that heat loss to the building adds to the cooling load during the summer and a finite amount of relatively expensive space must be provided.

When a storage unit is placed underground, the insulation must be of a material which will not absorb moisture. Neoprene foam or styrofoam could be suitable. The tank should be placed below the frost line unless a concrete lined pit is provided for the tank, pumps, and other equipment. The pumps, which circulate the storage water, should be placed at a level to prevent vapor locking at the impellers.

STORAGE SPACE

Precise heat storage sizing is not required for solar systems, but there is an economical size for a given installation. A very large volume of storage does not result in providing more solar heat to the building enclosure as compared to an adequately sized unit. Thus, a disproportionately large storage capacity relative to a fixed collector area is not useful.

A solar system that is to provide a major fraction of the annual heating load for a building should provide for overnight heating from the solar energy collected during an average winter day. If the previous day was cloudy, then the system will depend upon the back-up unit to provide heating. A large solar collector area which provides more heat than is needed by the building will have excess heat that can be stored in a large storage volume. Such a system could store enough heat for use over several days if there is no sunshine. The cost of the system increases, however, because of the larger collector area and storage volume. The most practical size to consider is a solar system that will provide for 20 to 30 hours of heating during average winter days. The recommended size of storage relative to collector area is one to two gallons of water for a liquid system, or one-half to one cubic foot of pebbles per square foot of collector area for an air system. A solar system for a residence with 500 square feet of collectors should have a storage unit with about 700 gallons of water capacity, or 300 cubic feet of pebbles. The installed cost of such a storage unit would range from $500 to $1,000.

STORAGE HEAT LOSS

If the heat storage unit is installed inside the building enclosure, the heat loss from the unit will be to the building interior. In the heating season the heat is effectively utilized, but in the summer the heat loss from storage will add to the cooling load. By placing the storage unit within a vented and insulated room, use of the heat loss from storage can be effectively controlled during winter and summer.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE B: SOLAR STORAGE

UNIT II: WATER STORAGE

UNIT OBJECTIVE

Upon completion of this unit the student will be able to discuss different heat storage media and to discuss sizing and location of the storage unit for specific requirements.

SPECIFIC OBJECTIVES

Upon completion of this unit, the student will be able to:

1. Select a storage unit appropriate for a particular type of solar system.
2. Size and locate the thermal storage unit.
3. Describe the various aspects in the design of water storage and rock bed storage.
4. Describe the various aspects involved for the proper functioning of water and rock storage.

MODULE B: SOLAR STORAGE

UNIT II: WATER STORAGE

HANDOUT 1: INTRODUCTION

Water should be used for heat storage if a liquid is used as the heat transport medium in the solar collectors. If an antifreeze solution is needed in the collectors, separate the fluid circulation loops with a heat exchanger between the collector and storage loops. If freezing is not of concern, water from storage may be circulated through the collectors without a heat exchanger and the storage water is pumped directly to the heating coils or the absorption cooling unit.

Four conditions must be avoided when using water for heat storage:

1. Freezing
2. Boiling and pressure build-up
3. Corrosion
4. Leakage

Because it is prohibitively expensive to provide ample antifreeze in a water storage tank to protect from freezing, it is recommended that the water storage tank be located inside the building or underground below the frost line. A storage tank inside the building is more desirable than one underground. Heat loss from underground tanks is not recoverable for useful purposes. Also, indoor tanks are more accessible for repairs.

Boiling and pressure build-up can occur in the storage tank and provisions should be made to prevent damage to the system or to the contents of the building. While it is an uncommon occurrence for well-designed systems during the heating season, frequent boiling may be expected during the summer if the heat is not used to operate a chiller. The steam can be vented outside the building to prevent pressure build-up in the tank and to release the heat from the system. A pipe from the top of the tank to the outdoors with a low pressure relief valve is sufficient. A float-controlled valve to provide make-up water in the storage tank should be provided. Boiling of storage water will cause build-up of mineral deposits with consequences in corrosion unless water softeners are used.

A high temperature shut-off control on the collector pump may be used with some collectors to avoid boiling. Many collectors, however, are not designed to withstand the high temperatures which result from no flow for an extended period; thus, the practice of stopping circulation is dependent upon the type of collector that is selected.

Corrosion is a potential problem whenever water is contained in a metal tank and the probability of corrosion greatly increases with temperature. Fiberglass lining to protect against corrosion and water softeners will increase the life of the tank but will be an added expense.

Corrosion usually occurs at the pipe connections to the tank. If dissimilar metals are used, galvanic corrosion will result. Therefore, neoprene rubber hoses should be used to connect copper pipes to steel tank fittings.

Water leakage must be prevented because it can damage tank insulation and other materials near the tank. Because there is difficulty in locating a leak after insulation is applied, the tank should be leak-tested with all fittings in place before insulation is applied.

HANDOUT 2: WATER STORAGE TANK

TANK MATERIALS

Tank materials most likely to be used in water storage are steel, aluminum, concrete, plastics, and fiberglass. Steel tanks should be lined with a material such as butyl rubber to prevent internal corrosion from the water. Any material used as a lining should have a long life since replacement may be quite difficult. The lining materials must withstand high temperatures that occur in the storage tank. Concrete tanks may not require lining, depending on quality, but do require additional reinforcing and sealing of joints because of temperature stresses from expansion and contraction. Most currently available plastic tanks will not withstand the temperatures needed in solar heating and solar cooling systems. Therefore, special composition tanks are required.

Concrete Tanks

Most concrete tanks are durable but difficult to install.

Some prefabricated units, such as septic tanks and large diameter pipes, may be assembled and used as water storage tanks or concrete tanks may be cast in place.

Although conductivity of heat through concrete is less than through metals, concrete tanks should be insulated to reduce heat loss. A high temperature sealant on the interior surface or a watertight liner is recommended to prevent seepage of water through the tank.

Fiberglass Tanks

Fiberglass tanks are corrosion resistant, but have limitations with regard to temperature. Although some fiberglass will withstand temperatures over 212°F, many fabricated tanks will not tolerate temperatures above 160°F. At high temperatures, the bonding resins in the fiberglass soften and the material begins to flow.

Glass-Lined or Galvanized Steel Tanks

Steel tanks are readily available and suitable for water storage. Glass-lined or galvanized steel tanks, while costing more, may be used to reduce the rate of corrosion inside the tank.

Tank Shape

A spherical tank provides the least surface area per unit volume of storage. It is the least expensive to insulate. A shape that deviates from this, such as a long slender cylinder, requires more tank insulation material.

A spherical tank is also structurally advantageous. However, fabrication and support of spherical storage tanks are more difficult than for cylindrical tanks. Thus, the most practical shape is a cylindrical tank having a diameter-to-width ratio of around one. Precast concrete tanks could be cylindrical or rectangular. Built-in-place reinforced concrete tanks would likely be rectangular because of easy forming.

Tank Location

If the tank is located within the building, there is some living area lost. Usually the most desirable location for the tank is in the basement. At this location the tank is easily accessible for repairs. In other cases, such as retrofit applications or where there is no basement, other convenient locations must be found. Alternatives are the garage or outside the house, either above or below ground.

Tank Size

Studies have shown that for most locations in the United States, the storage tank should be sized to hold from 1.5 to 2.5 gallons of water per square foot of collector area. A small storage tank will have higher average temperatures and hence, greater heat losses. However, high storage temperatures are necessary for present day air conditioning applications. The cut-off temperature for an absorption air conditioning unit is about 170°F. A large storage tank will have lower average temperature and may not be able to provide direct heating of the house. For most residential applications and locations, the system performance is relatively insensitive within the 1.5 to 2.5 gallon per square foot range.

Stratification

The top of the storage tank will generally be hotter than the bottom, and the magnitude of the temperature difference is a function of tank height and diameter. Any temperature stratification achieved is useful because the lowest temperature possible is pumped to the collector, which improves the performance of the collectors, and the highest temperature available is delivered to the heating coils to heat the house.

Actually, there is little stratification in a hot water storage tank. The difference in temperature of the water between the top and bottom of the tank is about 5°F during normal operation in 1000-gallon tanks. Stratification can be enhanced to some degree by the introduction of baffles to prevent convection and mixing. However, it is questionable that the gain is worth the expense. Another possibility is to use multiple tanks, but this adds to the expense of the installation.

Tank Piping

The inlet pipe to the storage tank from the collector should be located near the top of the tank, and the outlet to the collector should be near the bottom of the tank. The outlet from the tank for house heating and cooling should be close to the bottom of the tank. Vented tanks should be equipped with a make-up water line leading to the bottom of the tank with a float control valve.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE B: SOLAR STORAGE
UNIT II: WATER STORAGE

HANDOUT 3: WATER TANK INSTALLATION

TANK INSTALLATION FACTORS

Storage containers are normally the first of the solar components placed in the building during construction. Due to their size, it is advantageous to install the tanks before the building is enclosed. Exterior buried storage tanks may be installed after the building is erected and, economically, the excavation and concrete work for the storage tank should be scheduled with the building foundation work. Water storage tanks should be movable from the building because of the possibility of future replacement. If a large access for the tank is not possible in the building design, several smaller tanks may be clustered together, or the tank may be of a type that can be assembled and disassembled.

The storage tank should be well insulated on all surfaces, including the bottom. The bottom is more difficult to insulate because it must withstand the filled tank load (about 70 pounds per square foot for each foot of depth or 420 pounds per square foot for a six foot tall tank). Preferably, the insulation should be moisture-resistant. The side and top insulation, which may be fiberglass wool or foam insulation, may be installed later.

The pipe connections should be provided with the tank. Leak testing of all tank connections should be made before insulation is applied. Not only are leaks difficult to detect after being covered with insulation, the heat loss through wet insulation is so large that it is equivalent to no insulation. Standard plumbing precautions should be exercised by placing shut-off valves at strategic locations to isolate the tank, heat exchanger, and pumps. Drain connections should be provided with a valve and hose connection. Neoprene (high temperature) rubber hose connection between the tank and the piping is advised to prevent strain at the tank connection and to protect against corrosion where dissimilar metals are used.

Insulation

Insulation of a storage tank is important to conserve the collected heat. The bottom as well as the sides of the tank should be insulated. Tank bottom insulation must be accomplished prior to installation of the tank. There are several methods of doing this. One is to rest the tank on rigid insulation foam pads. Another method is to rest the tank on closely spaced two-by-six-inch boards and insulate between them.

Several different approaches can be used to insulate. One is to wrap the tank in conventional insulating material and another is to use a spray foam insulation. Insulation of at least R-20 is recommended for inside and R-30 for tanks placed outside. A type of insulation that will not absorb moisture should be selected for outdoor locations or for any area where water or moisture may present a problem.

It is also desirable to enclose the tank and the associated components--hot water heater and heat exchangers--in a vented, insulated room. This isolates the tank and other heat producing sub-systems from the rest of the house.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE B: STORAGE

UNIT III: ROCK STORAGE

UNIT OBJECTIVE

Upon completion of this unit the student will be able to distinguish and describe the design requirements for an efficient rock bed heat-storage unit.

SPECIFIC OBJECTIVES

Upon completion of this unit the student will be able to:

1. Select a suitable rock bed container.
2. Size and locate a rock storage unit.
3. Recognize potential maintenance features of rock storage units.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE B: SOLAR STORAGE

UNIT III: ROCK STORAGE

HANDOUT 1: INTRODUCTION

Heat is stored in a rock bed by circulating heated air from the collectors directly through the rock bed. In contrast to the water storage tank, the rock bed is not heated uniformly, but is heated gradually to the temperature of the air stream coming from the collector. This results in temperature stratification, where the top of a rock bed is at the collector air temperature and the bottom of the rock bed is at room temperature. The advantages in stratification are that cold air is returned to the collector so that the collector operates more efficiently. Also, the air temperature is high for heating from storage at night.

Solar heated air is passed directly through the rock bed from top to bottom. As the air passes through the pebbles, heat is transferred from the air to the rocks so that the rock temperature rises. The cool air which leaves the bottom of the rock bed is returned to the collectors to be reheated. The top of the rock bed will be warmer than the bottom because of hot air supply from the collectors. After sundown and the discontinuance of air circulation, the rock bed will maintain this temperature stratification because heat conduction through the bed from one pebble to another is small.

The stored heat is delivered to the building by circulating room air through the rock bed in the direction opposite that of the storing cycle, that is, from the bottom toward the top of the rock bed. As the cool air flows through the spaces between the pebbles, it is heated and the warm air is recirculated to the rooms. The bottom of the rock bed is always at the lowest temperature, usually room temperature, and because the coldest air is delivered to the collectors, the collectors operate at maximum efficiency.

The hot end, or collector supply end, of the rock bed is preferably at the top to prevent heat loss to the floor. If the layout requires the hot end at the bottom, two inches of rigid fiberglass board should be placed under the unit to reduce heat loss to the floor.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE B: SOLAR STORAGE

UNIT III: ROCK STORAGE

HANDOUT 2: ROCK BED CONTAINERS

CONTAINER MATERIALS

Rock beds may be contained in wood frame boxes, concrete block walls, or cylindrical steel bins. Wood frame boxes can be built in place where access is limited. Steel wire or tie rods should be placed across the box to prevent the sides from bulging under the pressure of the rocks. Framing should be of construction grade 2 x 4's on one-foot centers. One-half inch plywood can be used on both sides of the 2 x 4 studs and the space filled with fiberglass roll-insulation.

Steel bins make convenient rock bed containers. They can be assembled by bolting curved sections together on the job site. A durable caulking compound must be used at the joints to prevent air leakage. A two-inch foam insulation could be cut into segments and placed around the outside of the bin.

Concrete block may also be used for the rock bed walls. Steel reinforcement rods three-eighths inch in diameter should be placed across the bed every two to three feet to support the walls. Two-inch rigid fiberglass insulating board could be used to line the inside of the block walls.

A concrete bin is relatively economical when constructed with basement walls. Two additional walls in one corner of the basement level, with suitable openings, form the rock bin. Rigid insulation on the inside or outside can be added to reduce thermal losses. After filling, an insulated cover on a 2 x 4 frame can easily be installed.

ROCKS

Any type of rock suitable for concrete aggregate can be used in the rock bed. Size uniformity is important in order to provide proper air flow through the rock bed and graded gravel should not be used. One-inch concrete aggregate is screened so that the sizes vary from 0.75 to 1.5 inches and the aggregate is suitable for the rock bed.

The rocks should be free of fines, and concrete aggregate is normally acceptable. The bed should be filled by using a chute so that fracturing will be minimized and damage to the walls and bottom of the unit will be avoided.

The bin should be sealed before the rocks are placed to prevent air leakage. This is accomplished by caulking the joints with an epoxy or other suitable heat-resistant compound. Butyl rubber gasket or other heat-resistant material can be used to form the seal for the top lid. Air temperatures are nominally 150°F, but higher temperatures of 180° to 190°F are sometimes reached. Thus, sealant materials should be selected to withstand the higher temperatures.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE B: SOLAR STORAGE
UNIT III: ROCK STORAGE

HANDOUT 3: ROCK BED INSTALLATION

INSTALLATION FACTORS

A maximum depth of about six feet of rock is recommended for acceptable floor loading and air pressure loss. The pressure drop also depends upon size and uniformity of the pebbles. At a typical air velocity of about 20 feet per minute through five feet of 0.75 to 1.5 inch gravel, the pressure drop will be about 0.3 inch water guage.

Rock can be supported on a wire screen, such as expanded metal, which in turn is supported on bond beam blocks for maximum free area to air flow in the lower plenum. Coverage of the bottom by the supporting blocks should be about 50 percent for lightweight screen support. Block spacing can be greater for heavier mesh.

Although horizontal flow has occasionally been used in rock beds, heat exchange effectiveness has been lower than in vertical flow beds. With horizontal air flow the warm air tends to flow through the upper part and cool air through the bottom, the effectiveness of stratification is impaired.

a horizontal arrangement cannot be avoided, vertical baffles should be provided to prevent a "short circuit" when the rock settles. Commonly available rocks have a specific heat of about .21 BTU/(lb)(^{o}F). On a volume basis, the heat capacity is about 21 BTU/(ft^{3})(^{o}F)(.21 BTU/lb^{o}F x 100 lb/ft^{3}) for .75-to-1.75-inch rock sizes. This is one-third the heat capacity of water on a volume basis. Thus, to have the same heat storage capacity as a water tank, essentially three times greater rock volume is required. If the rock bed in a solar house contains 18 tons of .75-to-1.5-inch rocks in 363 cubic feet, 595,300 BTU can be stored (uniform temperature of 150^{o}F). If the outdoor temperature is 14^{o}F and the design heat load is 17,600 BTU/DD the solar house would have about 17 hours of heating stored.

The rock bed storage should be sized to provide 60 to 100 pounds of rock per square foot of collector. For normal rock densities and for .75-to-1.5-inch sizes, this is equivalent to one-half to one cubic foot per square foot of collector.

Ideally, a rock bed should have a short distance from inlet to outlet, with a large cross-sectional area perpendicular to the direction of air flow. With a large cross-sectional area, the air velocity is low and, with a short travel path through the rock bed, the pressure drop is small. The smaller pressure drop results in lower fan power.

The rock bed must be deep enough to permit stratification.

A minimum depth of 2.5 feet is suggested. To have adequate storage, however, the volume of the rock bed must be large. To avoid a large cross-sectional area, a larger depth may be used. When rock beds are constructed in the building, a depth of about six feet is allowable.

The rock size is relatively unimportant, although it affects the pressure drop through the bed. The rock size should not be so small as to reduce flow rates significantly, nor so large that the interior of individual rocks is never heated. It is recommended that rocks from .75 to 1.5 inches in size be used.

NEW BUILDING

The structural base for the rock-bed storage unit should be constructed during the foundation work of the building. The concrete base should be scheduled for pouring along with the concrete footings. If the storage container walls are to be concrete, the rock bed can be located in the corner of the basement to utilize common walls. If the container is to be fabricated of wood, the walls and insulation can be constructed prior to placement of the floor girders and joists.

The placement of temperature sensors for the control system and, if desired, for monitoring purposes, is a simultaneous activity with the filling of the rock bin. It is not practical to install sensors after the gravel has been placed in the bin.

COURSE VII: COLLECTORS AND ENERGY STORAGE

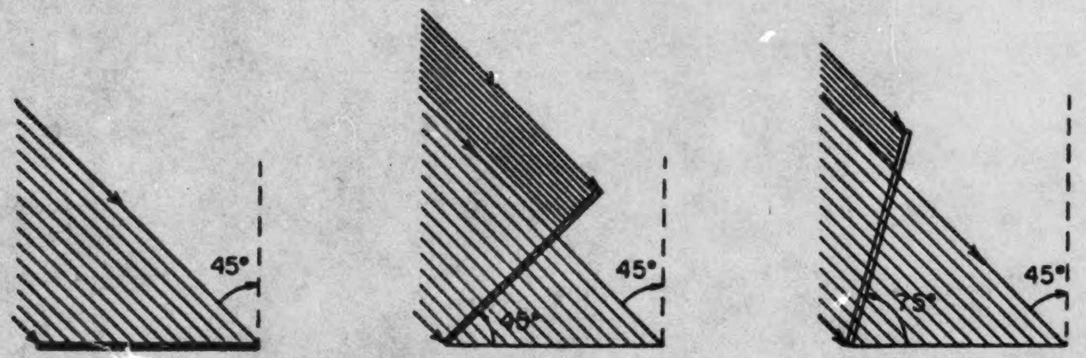
MODULE C: INSTALLATION

UNIT I: COLLECTORS

HANDOUT 1: POSITIONING

TILT

It is advantageous to tilt the collector perpendicular to the sun's rays. The increase in energy intercepted when a collector is tilted from the horizontal is illustrated below. Note that the optimum tilt angle places the collector at the same angle as the incoming radiation, as shown in (b). When the collector is tilted to an angle greater or smaller than the angle of the incoming radiation the additional energy intercepted is reduced, as shown in (c).



(a) Collector Tilt Angle 0°   (b) Collector Tilt Angle 45°   (c) Collector Tilt Angle 75°

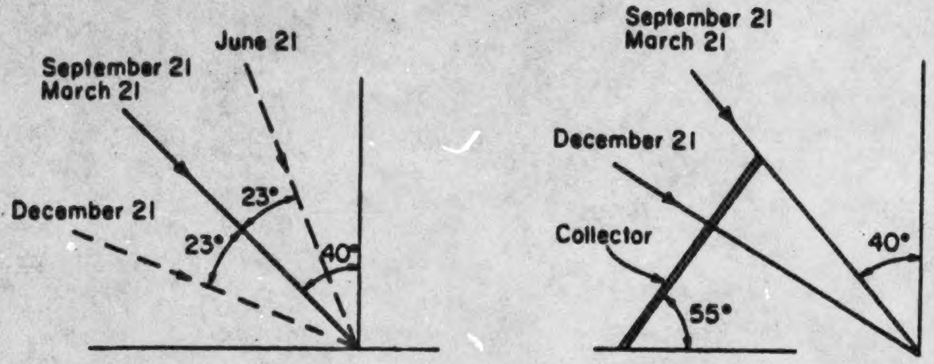
▤ Radiation Intercepted by a Horizontal Collector

■ Additional Radiation Intercepted by Tilting Collector

The maximum energy would be intercepted if the collector were to track the sun across the sky. This would mean both following the sun as it moved from east to west during the day and changing the collector tilt to coincide with the season. Tracking collectors are available, but are not as yet practical for use in residential solar heating systems.

A good compromise is to tilt the collector so that it is approximately perpendicular to the sun's rays at the time maximum collection is desired. The best angle for a specific location depends on the time of year, since the sun moves across the sky at a lower angle in the winter than in the summer. For heating purposes, maximum collection is desired during the coldest part of the heating season. During this season, from about October until March, the sun's angle varies from 5 degrees to 23 degrees below a line drawn at an angle from the perpendicular equal to the latitude of the location. To maximize collection during the heating season, a compromise is to tilt the collector at an angle of about latitude plus 15 degrees. Along the northern border of Kansas, latitude 40 degrees, the collector should be tilted at about 55 degrees for maximum collection during the heating season. This is illustrated on the top of the following page.

In the northern hemisphere the collector should be tilted to the south. To maximize summer collection the collector can be tilted to latitude minus 15 degrees. If both summer and


June 21
September 21
March 21
December 21
23°
23°
40°
September 21
March 21
December 21
Collector
40°
55°

(a) December 21, Sun 23° below Lat. Angle from Perpendicular
June 21, Sun 23° above Lat. Angle from Perpendicular
September 21 and March 21, Sun at Lat. Angle from Perpendicular

(b) Collector Tilted at Latitude +15° Maximizes Winter Collection.

(a) Variation of the Angle of Incoming Radiation with Season

(b) Collector Tilt to Maximize Winter Collection (Latitude 40°N)

winter collection are desired, a good compromise is to tilt the collector to an angle equal to the latitude.

ORIENTATION

Since the maximum intensity of direct radiation occurs at noon when the sun is due south, the direction of tilt for a collector should be directly south. If this is not feasible because of building considerations, a variation of 15 degrees east or west of due south can be tolerated without serious effect on the total energy collected. An orientation 15 degrees east of south will advance the time of peak collection one hour; an orientation 15 degrees west of south will delay the peak one hour. Perhaps a designer can take advantage of the change in peak collection. For example, if the collection location is partially shaded in the later afternoon, facing the collectors east of south would increase the morning collection.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE C: INSTALLATION

UNIT I: COLLECTORS

HANDOUT 2: SUPPORT

The support structure for solar collector modules or panels may be the vertical wall of the building or the roof trusses or rafters. The spacing between roof trusses, or wall studs, should be convenient for the type of collector to be used in the solar system. Loss of time in mounting collectors can be avoided with forethought given to convenient placement of purlins and nailers. Space must be allowed for manifold air ducts which will cross the roof trusses. The roof trusses should be made up of cross-pieces that will support the ducts.

The manifold which delivers air from the collector to storage is normally installed near the ridge of the roof. There should be sufficient space available to facilitate duct installations. Supports for collectors on flat roofs can be an integral part of the rafters, or the collector supports can be mounted above the finished roof.

Installation of collector modules can be scheduled simultaneously with the roofing and flashing. The collectors, in most instances, will replace the roofing, and should be rendered water-tight with cap strips between collector modules and flashing along the top, bottom, and sides of the collector array.

For heavy collector modules, a mechanical hoist such as a fork lift is helpful in installation. Although detailed instructions may be provided by the manufacturer for assembly of collector modules, considerable attention should be given to effect air-tight joints at all duct connections. Air leakage into the collector array can cause loss of heat from the system.

Piping to the air-water heat exchanger may be scheduled with the other building plumbing. All pipes should be leak-tested along with the other pipe joints.

If the control panel for the solar system is a separate unit, the installation can be scheduled with the other rough electrical work. The control panel should be located close to the solar system for convenience.

The rafters are normally the supports for the collector array; however, special supports may be required for some installations. When rafters are to support the collectors directly, some preplanning will reduce the labor costs to assemble and secure the collectors, particularly if the collectors are supported between the rafters. Collectors are usually mounted on plywood sheathing and the collectors are secured by bolts through the plywood.

Normally, pipe manifolds are placed along the ridge and eave of the roof. Provisions for easy access, not only for installation, but also for maintenance should be provided. Replacement of flexible connections between the collector panels and the manifold is a common maintenance item and, although replacement is simple, it can be made difficult with restrictive access, particularly the upper manifold.

Collectors mounted on flat roofs will require supports for tilting the collectors. The supports should be secured to the rafters, and open collector supports should be closed in to prevent wind drag and snow drifting, both of which will add extra loads on the roof.

Carefully inspect collectors before installation. Broken glass, improper seals, absorber plate conditions, and bad plumbing fittings are easy to identify. There is an advantage in placing liquid collectors tightly together side-by-side to minimize side heat losses from each collector module. When this cannot be done, insulation between the collector modules should be used to reduce the side heat losses. The manifolds should be connected to the collectors as the modules are installed to facilitate the connections. Although flexible connections will probably be used in most installations, the misalignment of a few collector modules can be cumulative, and even flexible hoses may become difficult to install if the collectors and manifold piping are not aligned properly.

The rough plumbing for the house and solar system can be scheduled simultaneously and, after placement of the control sensors, the various pipe loops can be leak-tested. A filter unit, all the valves, the heat exchanger, pumps, and an expansion tank should be installed in the collector loop.

The control temperature sensors can be installed in the storage tank and the collector outlet pipe manifold either before or after the leak tests.

COURSE VII: COLLECTORS AND ENERGY STORAGE

MODULE C: INSTALLATION

UNIT I: COLLECTORS

HANDOUT 3: LOCATION

If the slope and orientation of a roof is fitting, the most economical location for a solar collector in a residential domestic hot water and space heating system is on the south-facing section of the roof. The need and expense of an added structure to support the collectors is thereby eliminated, and pipe or duct connections to the conventional systems are usually convenient. In new dwellings, most installations can be expected on the house roof. Even in retrofitting existing dwellings, a suitable roof location can usually be provided.

If there are reasons in which the placing of collectors on the roof is impractical, a separate structure adjacent to the house may be used. A sloping platform supported on a suitable foundation can be the base for the collectors. Pumps, storage tank, and heat exchanger, if used, can be located inside the dwelling. Effective insulation on ducts and piping must be provided, however, so that cold weather operation will not be handicapped by excessive heat losses. In cold climates, collectors in which water is directly heated must be located so that drainage of the collector can be effectively accomplished.

PREREQUISITES: SOLAR ENERGY TECHNICIAN

1. The student must have the ability to use small machine and hand tools (electric drill, saw, pliers, hammers, and chisels).
2. The student must be able to weld, or learn how to weld.
3. The student must be able to lift 100 lbs over his/her head.
4. The student must be able to read at the fifth-grade level.
5. The student must be able to work in environments of extreme cold and hot climates, from -20° to +98°F.
6. The student must be able to work in close confines.
7. The student must be physically fit and cannot have physical handicaps of the type that would restrict the student from job duties. A student must be able to work on the roof of a house or apartment without getting dizzy.
8. The student must be able to be bonded.
9. The student should have an interest in air conditioning (HVAC) and/or plumbing.
10. Student should be interested in solar as an alternate source of energy.
11. A high school diploma or GED equivalency is desired but not required.
12. Assume knowledge of basic arithmetic operations, including addition, subtraction, multiplication, and division. Must be able to read charts.
13. Normal color vision is desired, but not essential.

COURSE VIII: SOLAR HEATING AND COOLING SYSTEMS

MODULE A: SYSTEM DESIGNS

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COURSE VIII: SOLAR HEATING AND COOLING SYSTEMS

MODULE A: SYSTEM DESIGNS

UNIT I: INTRODUCTION TO SOLAR SYSTEMS

HANDOUT 1: INTRODUCTION

Any system which utilizes solar energy to heat and/or cool a building can be defined as a solar heating and/or cooling system, however a distinction is often made between "passive" and "active" systems. A passive system can be defined as having no moving parts, although it may involve natural circulation of fluid to the heated space. A south-facing window or skylight which transmits sunlight can be considered a passive system if it admits more energy than it loses as heat. Another type of passive system may involve movable insulation material which reduces heat loss from solar absorber surfaces when there is no sunshine. In contrast to a passive system, an active system involves hardware to collect solar energy, store heat, and distribute the heat to the rooms in a building.

The emphasis in this course is on active solar systems which provide controlled collection and distribution of solar heat. Active systems can be integrated directly into conventional HVAC systems in buildings.

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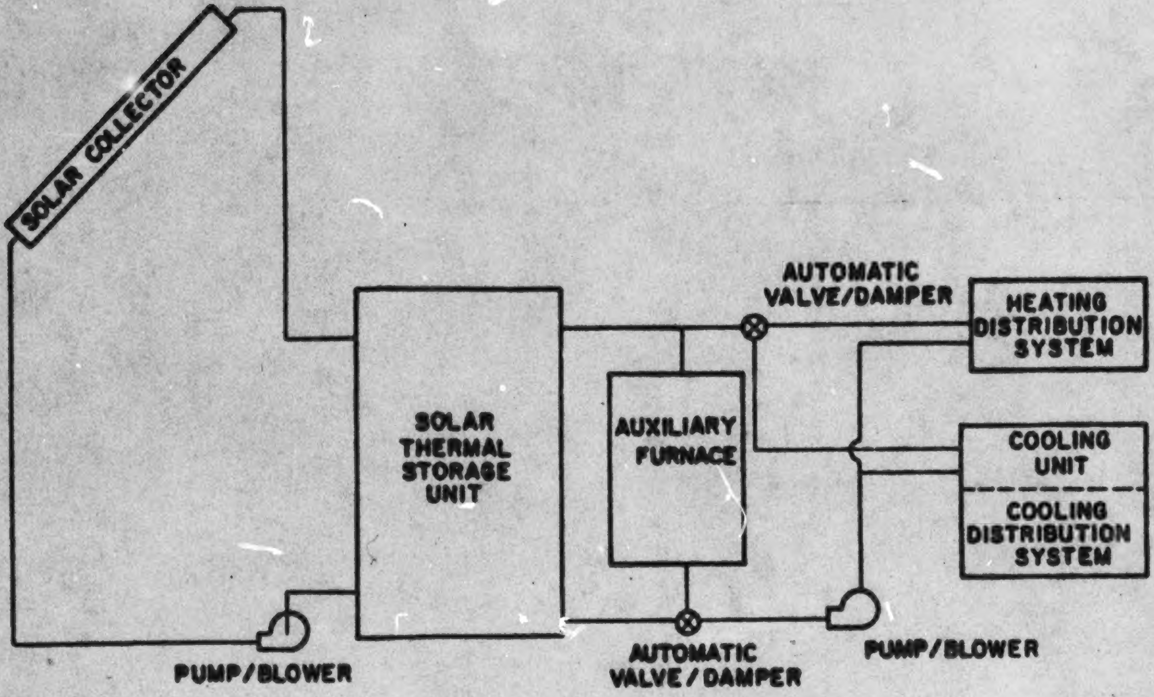

SOLAR COLLECTOR
AUTOMATIC VALVE/DAMPER
HEATING DISTRIBUTION SYSTEM
SOLAR THERMAL STORAGE UNIT
AUXILIARY FURNACE
COOLING UNIT
COOLING DISTRIBUTION SYSTEM
PUMP/BLOWER
AUTOMATIC VALVE/DAMPER
PUMP/BLOWER

Schematic Drawing of a Solar Heating and Cooling System

The above schematic drawing of an active solar heating and cooling system is a representative of those available today. The key elements are a solar collector, a heat storage unit, an auxiliary furnace, a heat-transfer circuit (pumps, blowers, etc.), a method of delivering heat to the house, and a cooling machine for space cooling. Plus, many solar systems include facilities for providing solar heat to the domestic hot water system.

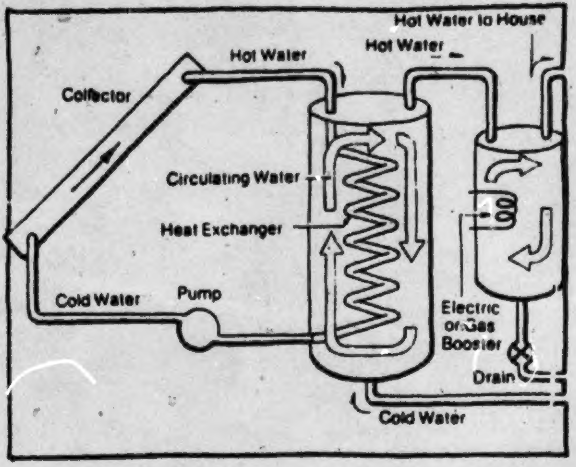
Operationally, the solar collector intercepts solar radiation, converts it to heat and, utilizing some heat-transfer fluid, transfers the collected energy to a thermal storage unit (or, in some cases, directly to the heating load). The thermal storage unit is an essential element because it provides for the use of solar generated heat to be available during periods of low solar radiation and at night. In general, the solar collector and thermal storage unit can operate independently of any heating or cooling requirement, and can be collecting and storing solar energy whenever there is sufficient incident solar radiation.

An auxiliary furnace is required as a back up to the heating/cooling system for periods of the year when the solar collector/thermal storage subsystem is unable to meet the heating/cooling demands. While the solar collector could be sized large enough to provide the full heating load throughout the year, this is not as economical as an auxiliary assisted system. It is preferable to have an auxiliary furnace or boiler capable of meeting the full heating/cooling demand (at design conditions) and use this auxiliary during periods of high heating/cooling demands and low solar availability.

There are several ways to accomplish heat delivery to the building. In an air system the solar heated air can be taken directly from either the solar collector or the thermal storage unit and delivered to the building by utilizing a blower and duct distribution. In a liquid system a liquid-to-air heat exchanger can be used to provide heat to a central air distribution system, or the liquid can be piped directly to the heated space, where separate fan coil units can be used to heat the building.

A number of different methods can be used for cooling. These include absorption cooling units (both lithium-bromide and ammonia-water systems), Rankine cycle vapor-compression, and others. (However, only the lithium-bromide absorption unit is commercially available and it has been used only in experimental installations.) Alternatively, a heat pump might be utilized as a conventional cooling unit (powered by electricity) and used as the auxiliary for the solar space heating system.

A typical schematic drawing (at right) shows the arrangement of components for utilizing solar heat in a domestic hot water system (DHW). Solar energy from a collector or a thermal storage unit is used to preheat the domestic hot water available from the cold water main. As hot water is used in


Hot Water to House
Hot Water
Hot Water
Collector
Circulating Water
Heat Exchanger
Cold Water
Pump
Electric or Gas Booster
Drain
Cold Water

the building, the preheated water replaces the hot water taken out of the auxiliary hot water tank. Conventional fuels such as gas or electricity are used to boost the temperature of the preheated water to the desired temperature (e.g., 140°F), and/or to maintain the temperature of the water remaining in the auxiliary tank at the desired temperature. During the summer a solar thermal storage unit provided as part of the heating and cooling system can normally meet one hundred percent of the domestic hot water load.

In addition to the components of conventional heating and/or cooling systems normally required to meet the heating and cooling loads, a solar system requires the addition of solar collectors, thermal storage units, DHW preheat tanks, some additional plumbing/sheet metal work, and more extensive control systems. The emphasis of this course will be to provide the details of these additions to the conventional systems and the interfaces between the solar subsystem and the conventional HVAC components. Of the additional solar components, the most important is the solar collector.

COURSE VIII: SOLAR HEATING AND COOLING SYSTEMS

MODULE A: SYSTEM DESIGNS

UNIT I: INTRODUCTION TO SOLAR SYSTEMS

HANDOUT 2: COLLECTORS AND SOLAR STORAGE

COLLECTORS

Review "Module A: Collectors" which may be found under "Course VII: Collectors and Energy Storage".

SOLAR STORAGE

Review "Module B: Solar Storage" which may be found under "Course VII: Collectors and Energy Storage".

COURSE VIII: SOLAR HEATING AND COOLING SYSTEMS

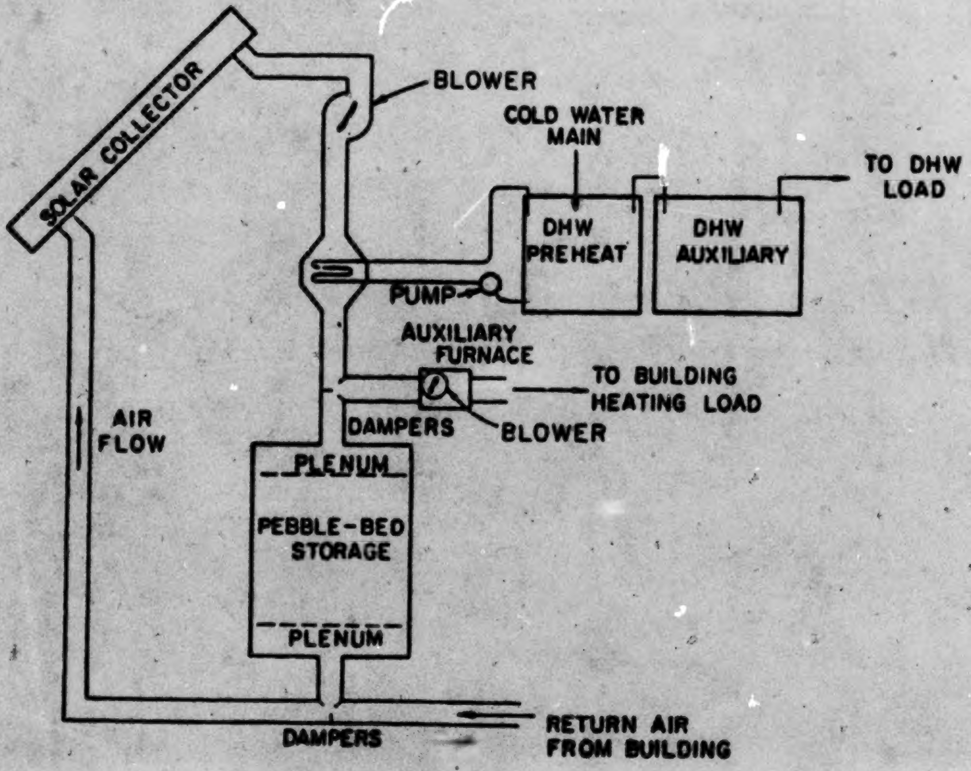
MODULE A: SYSTEM DESIGNS

UNIT I: INTRODUCTION TO SOLAR SYSTEMS

HANDOUT 3: MODES OF OPERATION

AIR SYSTEMS

The collection and storage of solar-generated heat can be accomplished in a variety of ways. An example of a solar heating system is shown below:


SOLAR COLLECTOR
BLOWER
COLD WATER MAIN
TO DHW LOAD
DHW PREHEAT
DHW AUXILIARY
PUMP
AUXILIARY FURNACE
TO BUILDING HEATING LOAD
AIR FLOW
DAMPERS
BLOWER
PLENUM
PEBBLE-BED STORAGE
PLENUM
DAMPERS
RETURN AIR FROM BUILDING

Solar Air Heating System

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The components of this typical unit include:

1. a fixed solar air-heating collector having a flat absorber and heat exchanger plate.
2. a control unit which includes the sensors and control logic necessary to automatically maintain constant comfort conditions.
3. a pebble-bed heat storage unit which heat is transferred to and from by circulating air through the bed.
4. an air handling module comprising automatic dampers, filters, and blower(s).
5. a solar hot water heater consisting of an air-to-water heat exchanger and a preheat storage tank connected to an auxiliary hot water heater.
6. an auxiliary heating unit, usually a warm-air furnace, to provide one hundred percent back-up space heating when storage temperatures are insufficient to meet demands or when the solar system is not operating.

In the air heating system the collector absorbs solar radiation and converts it to heated air for space heating. Circulation is from the solar system to the building in the same manner as in most modern warm air heating systems. Air is circulated from one end of the collector to the other, its temperature normally rising from 70 degrees to 130 to 150 degrees during the mid-part of the day. The building is heated directly from the collector whenever heating is needed during sunny periods. Cool air from the building is returned to the collector for reheating.

The heat storage unit utilizes the heat exchange and heat storage characteristics of dry pebbles, the most practical storage medium for use with air heating collectors. When heat is not needed in the building, solar heated air is routed through the storage unit where the pebbles are heated. The cool air, usually at 70°F, returns to the collector for reheating. Temperature stratification in the storage unit assures maximum heat recovery from the solar air collector. In the evening and night-time hours, heat is delivered to the rooms by circulating air from the building through the pebble bed. Because of temperature stratification in the storage unit, this mode provides heat to the rooms at the highest available temperature. The system automatically provides auxiliary heating from fuel or electricity when solar heat is not available from either the collector or storage.

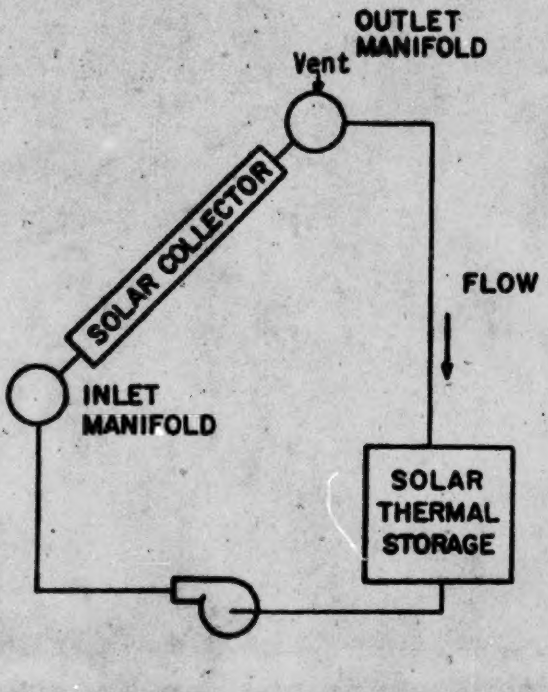
Domestic hot water can be made available by inserting a hot water heat exchanger in the hot air duct from the collectors. Thus, solar energy can provide preheated water whenever the collector is in operation.

At the present time, no cost effective cooling equipment is commercially available for operation by means of solar heated air.

LIQUID SYSTEMS

The connection between the solar collector and the thermal storage unit may be more complicated in a liquid system then in an air system. The complication is due to factors such as corrosion, freezing, and the use of different loops. In nearly all practical liquid systems, heat is stored hot water in a well-insulated tank.

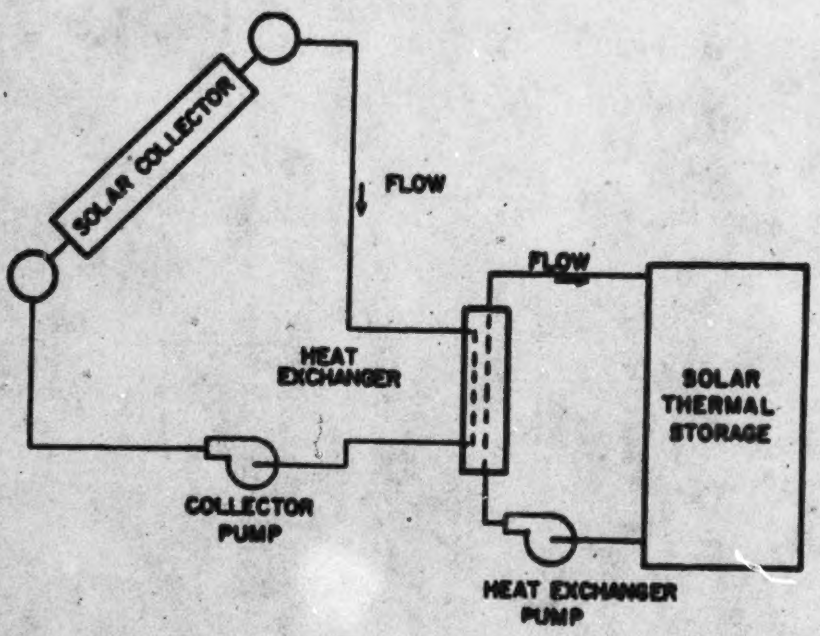
If water is used in the solar collectors in a cold climate, some freeze protection method must be used. The most direct method is to allow the collector to drain into the storage tank whenever the pump turns off. A liquid system solar collector is shown below:


OUTLET MANIFOLD
Vent
SOLAR COLLECTOR
FLOW
INLET MANIFOLD
SOLAR THERMAL STORAGE

Solar Collector (Liquid System)

When the solar intensity is sufficient for heat collection, a pump circulates water through the collectors and the thermal storage unit. When the pump shuts off, the water in the collector drains into the storage tank. A vent is provided at the top of the collector so that air can enter the collector tubes as water drains out.

The following illustration shows an alternate method wherein propylene glycol is used with water in the collector loop. To avoid the cost of a large quantity of glycol in the storage liquid (approximately 250 gallons or more of antifreeze)


SOLAR COLLECTOR
FLOW
FLOW
HEAT EXCHANGER
SOLAR THERMAL STORAGE
COLLECTOR PUMP
HEAT EXCHANGER PUMP

Collector Loop with Heat Exchanger

a heat exchanger is inserted between the collector and storage tank. An additional pump is usually required, depending on the location and type of heat exchanger.

The advantage of this design is that there is no risk of freezing (and damage) from improper collector draining or venting, nor from corrosion caused by the alternating exposure of the collector tubes to water and air. The possibility of corrosion and freezing can thus be compared with the cost penalty of the exchanger, pump, and additional piping for the design.

A more significant factor is the "driving temperature" across the heat exchanger. Typically the collector fluid operates 10 to 15 degrees hotter than storage. This higher temperature results in a decrease in collector efficiency.

Another important consideration involving the system is the effect of a power failure. In this event, circulation ceases and, usually in a few minutes, the collector fluid begins to boil. A pressure - relief mechanism should always be included in the system so that over-pressure will not occur and the steam can escape. The problem occurs when the power returns and there is insufficient fluid in the collector loop to prime the pump and achieve circulation. There is a design to partially alleviate this problem by providing make-up water (either from a tank or directly from the water supply) but the loss of antifreeze may require manual addition.

COURSE VIII: SOLAR HEATING AND COOLING SYSTEMS

MODULE A: SYSTEM DESIGNS

UNIT I: INTRODUCTION TO SOLAR SYSTEMS

HANDOUT 4: DISTRIBUTION

SOLAR

Distribution of solar heated and cooled air in a building can be the same as in any other commercial heating/cooling system. In "hydronic" types, water can be piped from storage to coils imbedded in floors or ceilings (radiant heating) or to "radiators" or fan-coil units in individual rooms. The operating temperature requirements of baseboard hot water heating are usually too high for use with a solar system, unless dual baseboard circuits are provided, one for the solar heated water and one for conventional heating. But most solar heating systems employ central forced air distribution. Hot water from the solar storage tank is piped to a heating coil in which circulating air picks up the heat for delivery to the rooms. For cooling, hot water from the solar storage tank can be piped to an air conditioner, where it provides the energy to operate a lithium bromide absorption cooling unit. An evaporator coil in the air duct cools and dehumidifies the circulating air.

Other than heating and cooling the house, solar energy may be used to provide most of the domestic hot water needs. Water from a cold water main enters the preheat tank from which it is circulated through a heat exchanger, where it is heated by hot water from the solar storage tank. When a hot water faucet is opened, water from the preheat tank enters a conventional gas or electric hot water heater where the water temperature can be increased (if needed) before passing to the distribution piping.

AUXILIARY

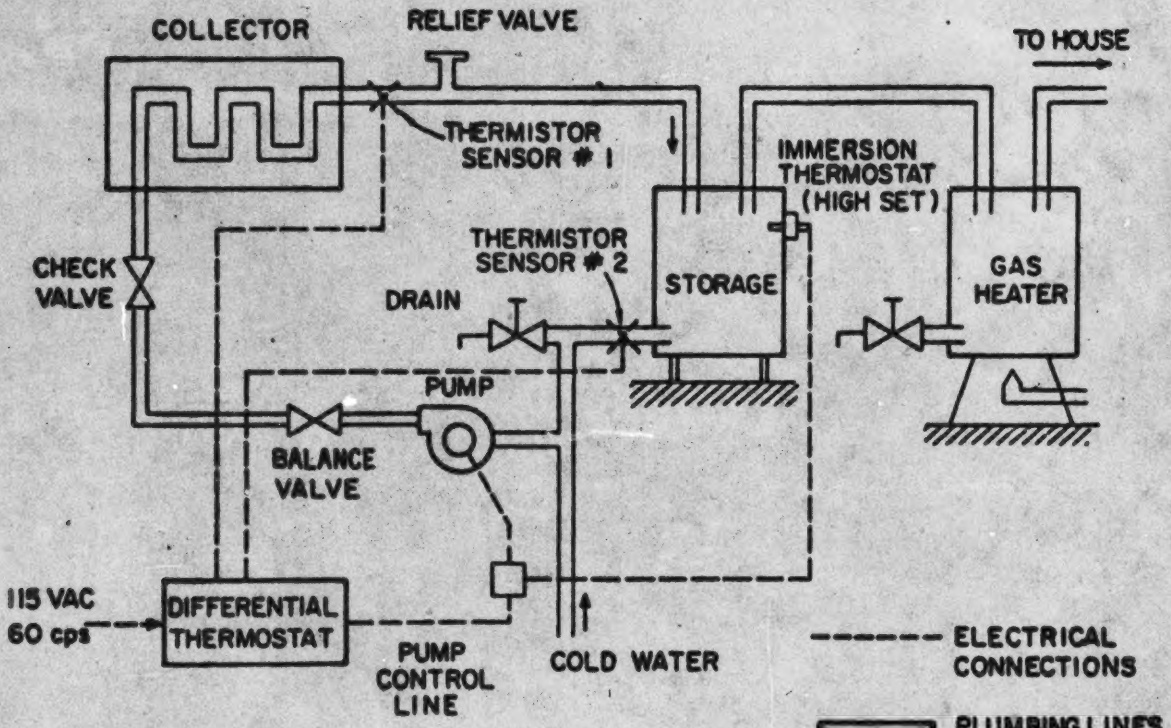
During cloudy periods and in midwinter, the solar system may not be able to meet all of the heating or cooling needs of the building. With a liquid system, a conventional hot water boiler may be provided to supply part or all of the heating or cooling requirements during these periods. If the temperature in the solar storage tank drops below a preset point (e.g., 100°F for heating, 170°F for cooling). the auxiliary boiler automatically supplies hot water to the heating coils or the air conditioning unit.

A warm air furnace may be used for supplying auxiliary heat (not usable for cooling) if the building is provided with a warm air heating system. This form of auxiliary heat is nearly always used with air collectors and pebble storage, and is often the choice when liquid collectors and liquid-to-air heat exchanges are employed. The furnace may also be replaced by an air-to-air heat pump in air systems.

In a solar heating and cooling system, the auxiliary unit supplies energy for both the heating and cooling functions and operates as a "replacement". If solar heat is unavailable (either from the collector or from storage) the auxiliary delivers heat for the entire load. Heating or cooling is accomplished either with solar or auxiliary energy. An alternative is to use the auxiliary to "boost" the temperature of the solar heated fluid (air or water). This is ideal for an air distribution system but should not be used in a water loop.

The homeowner needs only to set the thermostat to control the temperature in a conventionally heated home. A well designed solar heating and/or cooling system is the same, except, the controls are necessarily more complex than in a conventional system, because they must control collector and storage pumps or blowers and automatic valves or dampers in addition to the usual functions. An example of a solar control schematic for a domestic hot water system is shown on the following page.

The differential thermostat senses the difference in temperature at collector outlet and the storage tank. When this difference is more than a few degrees, the circulating


COLLECTOR
RELIEF VALVE
TO HOUSE
THERMISTOR SENSOR # 1
IMMERSION THERMOSTAT (HIGH SET)
CHECK VALVE
THERMISTOR SENSOR # 2
STORAGE
GAS HEATER
DRAIN
PUMP
BALANCE VALVE
115 VAC 60 cps
DIFFERENTIAL THERMOSTAT
PUMP CONTROL LINE
COLD WATER
ELECTRICAL CONNECTIONS
PLUMBING LINES

Typical Control System

pump is started. The high set thermostat prevents too high a temperature in the preheat tank by cutting power to the collector pump. A pressure relief valve protects the system from excessive pressure, which might otherwise develop if there is no circulation through the collector during a sunny session.

A number of controllers for solar space heating systems are commercially available, and many varieties of control circuits and methods are being used. Design of control systems requires directions from the manufacturersof the control components and experience in their proper integration and adjustment.

COURSE VIII: SOLAR HEATING AND COOLING SYSTEMS

MODULE A: SYSTEM DESIGNS

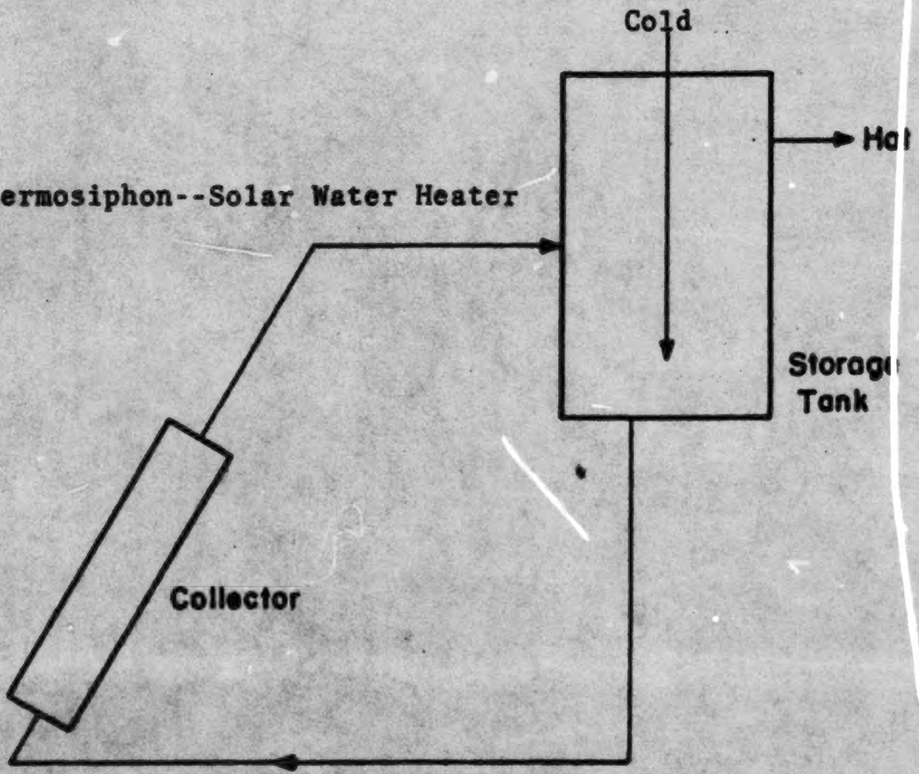
UNIT II: TYPES OF SOLAR SYSTEMS

HANDOUT 1: DOMESTIC HOT WATER

Using the sun to heat our hot water the year around is and has been the most practical use of solar energy.

PASSIVE SYSTEM--DIRECT HEATING
(Warm Climate)

In non-freezing climates a thermosiphon solar water heater is used. A diagram is shown below.


Thermosiphon--Solar Water Heater

The collector, usually single glazed, may vary in size from about 20 square feet to 100 square feet and the insulated storage tank may range from 30 to 120 gallon.

Operation at supply pressure can be provided if the system is so designed. With a float valve in the storage tank or in an elevated head tank, unpressurized operation can be obtained if the system is not designed for pressure. Gravity flow from the hot water tank to hot water faucets would have to be accepted, or an automatic pump would have to be provided in the hot water line to supply pressure service. Plumbing systems and fixtures in the United States usually require the pressurized system.

Location of the tank higher than the top of the collector permits circulation of water from the bottom of the tank through the collector and back to the top of the tank. The density difference between cold and hot water produces the circulating flow. Temperature stratification in the storage tank allows for operation of the collector under most favorable conditions, water at the lowest available temperature being supplied to the collector and the highest available temperature being provided to service. Circulation occurs only when solar energy is being received, so the system is self-controlling. The higher the radiation level, the greater the heating and the more rapid the circulating rate will be.

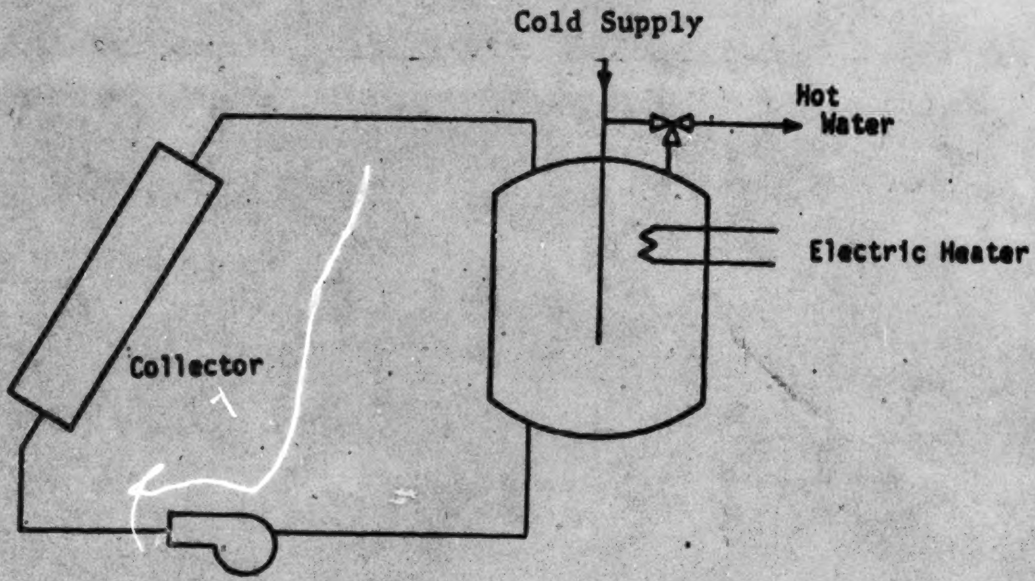
In a typical collector under a full sun, a temperature rise of 15°F to 20°F is commonly realized in a single pass through the collector.

To prevent reserve circulation and cooling of stored water when no solar energy is being received, the bottom of the tank should be located above the top header of the collector. If the collector is on a house roof, the tank may also be on the roof above the collector or in the attic space at a height that exceeds the top header of the collector.

Do not use the thermosiphon system in cold climates without researching a collector draining technique.

ACTIVE SYSTEM--DIRECT HEATING
(Warm Climate)

If placement of the storage tank above the collector is not convenient or not possible, the tank may be located below the collector and a small pump used for circulating water between collector and storage tank. This arrangement is usually more practical than the thermosiphon type in the United States, because the collector would often be located on the roof with a storage tank in the basement. Instead of thermosiphon circulation when the sun shines, a temperature sensor actuates a small pump which circulates water through the collector-storage loop. A schematic arrangement is shown on the following page. To obtain maximum utilization of solar energy, control is based on the difference in water temperature at collector outlet and bottom of storage tank.



Direct Heating--Pump Circulating

Whenever this difference exceeds a preset number of degrees the pump motor is started. The sensor at the collector outlet must be located close enough to the collector so that it is affected by collector temperature even when the pump is not operating. Similarly, the sensor in the storage tank should be located in or near the bottom outlet from which the collector is supplied. When the temperature difference falls below the preset value, the pump is shut off and circulation stops. To prevent reverse thermosiphon circulation and consequent water cooling when no solar energy is being received, a check valve should be located in the collector feed-side of the circulation line.

If hot water consumption is not sufficient to maintain storage tank temperature at normal levels, boiling may occur in the collector. If a check valve or pressure-reducing valve prohibits back flow from the storage tank into the main, a relief valve must be provided in the collector-storage loop. The relief valve will permit the escape of steam and prevent damage to the system.

ACTIVE SYSTEM--DIRECT HEATING
(Cold Climate)

If the solar water heater described above is used in a cold climate, it may be protected from freeze damage by draining the collector when sub-freezing temperatures are encountered. Several methods can be used. Their common requirement, however, is reliability, even when electric power may not be available.

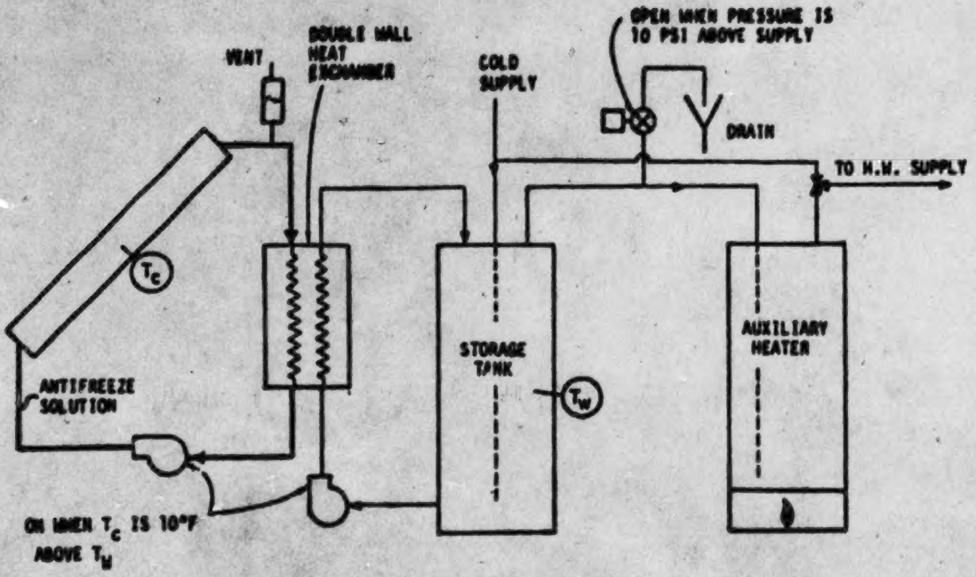
Drainage of the collector in freezing weather can be accomplished by automatic valves which provide water outflow to a drain and the inflow of air to the collector. The control system can be arranged so that whenever the circulating pump is not in operation, these valves are open. To assure maximum reliability, the valves should be mechanically driven to the drain position (by springs), rather than electrically, so that in the event of a power failure, the collector can automatically drain.

The drainage system is actuated by a temperature sensor in the collector. When the sensor indicates a possibility of freezing, it can open drainage and vent valves, thus providing protection. The temperature sensor can be of the vapor pressure type, with capillary tube connections to mechanical valve actuators, or of the electrical type where the valves are held open by electrical means, automatically closing either when electrical failure occurs, or at low temperatures.

ACTIVE LIQUID SYSTEM--INDIRECT HEATING
(Cold Climate)

As can be inferred from the above discussions of needs and means for collector drainage in freezing climates, costs and hazards are involved with those systems. The drainage requirement can be eliminated by the use of a non-freezing heat transfer medium in the solar collector, and a heat exchanger for transfer of heat from the solar heat collecting medium to the service water. The collector need never be drained, and there is no risk of freezing and damage. Corrosion rate in the wet collector tubes is also decreased when intermittent admission of oxygen is not permitted.

The following page illustrates a method for solar water heating with a liquid heat transfer medium in the solar collector. The most commonly used liquid is a solution of propylene glycol in water. A pump circulates this unpressurized solution, as in the direct water heating system, and


VENT
DOUBLE WALL HEAT EXCHANGER
COLD SUPPLY
OPEN WHEN PRESSURE IS 10 PSI ABOVE SUPPLY
DRAIN
TO H.W. SUPPLY
T_C
STORAGE TANK
T_W
AUXILIARY HEATER
ANTIFREEZE SOLUTION
ON WHEN T_C IS 10°F ABOVE T_W

Dual Liquid Solar Hot Water Heater

delivers the liquid to and through a liquid-to-liquid heat exchanger. Simultaneously, another pump circulates domestic water from the storage tank through the exchanger, back to storage. The control system is essentially the same as that in the design employing water in the collector directly. If the heat exchanger is located below the bottom of the storage tank, and if the pipe sizes and heat exchanger design are adequate, thermosiphon circulation of water through the heat exchanger can be used. A small expansion tank needs to be provided in the collector loop, preferably near the high point of the system, with a vent to the atmosphere.

To meet most code requirements, the heat exchanger must be of a design such that rupture or corrosion failure will not permit flow from the collector loop into the domestic water, even if pressure on the water side of the exchanger drops below that on the antifreeze side. A conventional tube-and-shell exchanger would therefore not usually be acceptable. Similarly, a coil inside the storage tank, through which the collector fluid is circulated, would not be satisfactory. Parallel tubes with metal bonds between them, so that perforation of one tube could not result in liquid entry into the other tube, would be a suitable design. A finned tube air-to-liquid heat exchanger could also be used by circulating the two liquids through alternate rows of tubes, heat transfer being by conduction through the fins.

Although an aqueous solution of propylene glycol appears to be the most practical for solar energy collection, organic liquids such as Dowtherm J and Therminol 55 may be employed. Price and viscosity are drawbacks, but chemical stability and assurance against boiling are advantages over the antifreeze mixture.

ACTIVE AIR SYSTEM--INDIRECT HEATING

In a manner similar to that described immediately above, solar energy can be employed in an air heating collector with subsequent transfer to domestic water in an air-to-water heat exchanger. A solar air heater is supplied with air from a blower, the air is heated by passage through the collector, and the hot air is then cooled in the heat exchanger through which domestic water from a storage tank is either being pumped or is circulating by thermosiphon action. Air from the heat exchanger is recirculated to the collector. Differential temperature control (between collector and storage) is employed as in the other systems described. Advantages of the air heat transfer medium are the absence of corrosion in the collector loop, freedom from liquid leakage, and freedom from boiling and loss of collector fluid. Disadvantages are the larger conduit between collector and heat exchanger, higher power consumption for circulation, and slightly larger collector surface requirements.

AUXILIARY HEAT

A dependable supply of hot water requires the availability of auxiliary heat for supplementing the solar source. The numerous methods of providing auxiliary heat vary in cost and effectiveness. A general principle for maximizing solar supply and minimizing auxiliary use is the avoidance of direct or indirect auxiliary heat input to the fluid entering the solar collector. If auxiliary heat is added to the solar hot water storage tank, so that the temperature of the liquid supplied to the collector is increased above that which only the solar system would provide, efficiency is reduced because of higher heat losses from the collector. Thus, auxiliary heat should be added at a point beyond (downstream from) the solar collector-storage system. Any deficiency in temperature is made up by fuel in the conventional heater with a thermostat. Alternatively, a "fast response", in-line heater can be employed. It is evident that auxiliary heat supply in these designs cannot adversely affect the operation of the solar system.

Another way in which auxiliary heat can be used without reducing solar collection efficiency is by electric resistance heaters in the upper portion of the solar storage tank. Temperature stratification in the tank, accomplished by bringing cold water from the main into the bottom and by circulating through the collector from the bottom of the tank to the upper portion of the tank, thereby prevents auxiliary heat from increasing the temperature of the water supplied to the collector. Water returning from the collector may be brought into the tank well below the level of the resistance heater so that the hot supply is always available at the thermostatted temperature. If relatively high temperature water is desired, there may be an undesirable influence of auxiliary supply on collector efficiency because of some mixing in the tank.

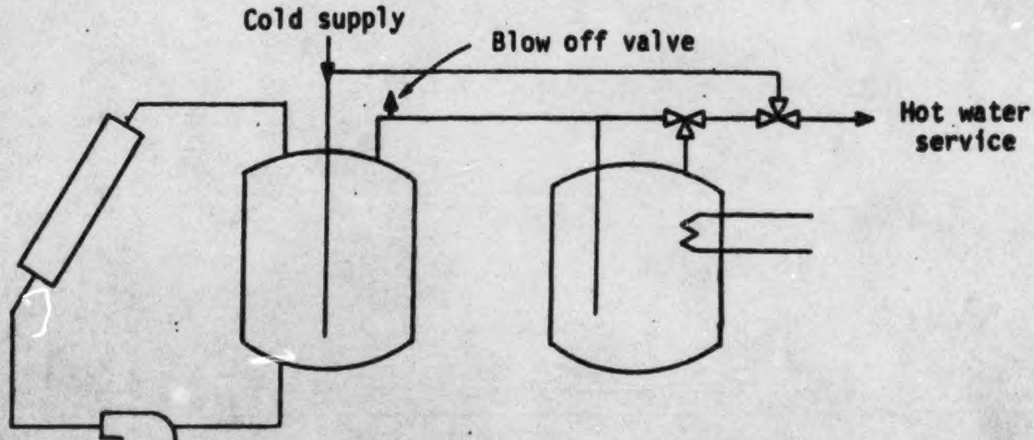
Although the description of the above systems refers to direct circulation of water through the collector, the same factors apply to the systems involving heat exchange with antifreeze solutions or air circulating through the collector. In all cases, auxiliary heat should be supplied downstream from the solar storage tank, regardless of whether the water itself is circulated through the collector or whether heat is exchanged between the domestic water and a solar heat transfer fluid.

TEMPERATURE STRATIFICATION IN SOLAR HOT WATER STORAGE TANK

As in a conventional hot water heater, the temperature in the upper part of a solar hot water tank will normally be considerably higher than at the bottom. The lower density of hot water allows this stratification, provided that turbulence at inlet and outlet connections is not excessive. The supply of relatively cold water from the bottom of the tank to the collector allows the collector to function at its highest possible efficiency under the prevailing ambient conditions. With a circulation rate such that a temperature rise through the collector of 15°F to 20°F occurs, the lower part of the storage tank is furnished to the collector for maximum effectiveness. If very little hot water is withdrawn from the tank during a sunny day, the late afternoon temperature at the bottom of an 80 gallon tank connected to a 40-to-50 square foot collector may be well above 140°F--even nearing the temperature in the top of the tank. Collection efficiency thus varies throughout the day, depending on solar availability and on the temperature of water supplied to the collector from the tank bottom.

TEMPERATURE CONTROL LIMIT

In addition to the differential temperature control desirable in most solar water heating systems (which sense temperature difference between collector and storage), protection against excessive water temperature may be necessary. A number of possible methods can be used. In practically all types of systems, whether direct heating of the potable water or indirect heating through a heat exchanger, a thermostatically controlled mixing valve can be used to provide constant temperature water for household use. The following diagram illustrates one method by which this type of temperature control can be accomplished.



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Cold water is entered into the hot water line immediately downstream from the auxiliary heater in sufficient proportion to secure the desired preset temperature. The solar hot water tank is permitted to reach any temperature attainable, and the auxiliary heater provides additional energy only when the auxiliary tank temperature falls below the thermostat set point. Maximum solar heat delivery is thus achieved, and no solar heat needs to be discarded except that which might sometimes be delivered when the main storage (preheat) tank is at the boiling point. Any additional solar heat collected under that condition will be dumped through a pressure relief valve, letting steam escape to the surroundings.

An option, that appears considerably more practical than the pressurized collector required with aqueous systems if the dual-liquid design is utilized, is to use heat transfer fluids having high boiling points. Downtherm J or Therminol 55 have boiling points above 300°F, so if one of these fluids is used, the development of pressure in the collector loop would not occur, even when the storage system is venting steam at 50 psi.

Another option for high-temperature protection is available if the collector is used as a heater for a high-boiling organic liquid or for air. To prevent the storage tank from reaching a temperature higher than desired, a limiting thermostat in that tank can be used simply to discontinue circulation of the heat transfer fluid (organic liquid or air) through the collector and heat exchanger. No additional heat is therefore dissipated in the form of collector heat loss. The collector temperature rises substantially, frequently above 300°F, but if properly designed, the collector suffers no damage. This system is probably the safest and most dependable of those herein described. With a reliable limit switch in the storage tank, there can be no dangerous pressure developments anywhere in the system. In addition, there is no loss of water (in the form of steam) even when there is no use of hot water for long periods.

Most single-glazed collectors will reach a maximum temperature--heat lost from collector is equal to heat gained by the collector--somewhat below the temperature of boiling water. A single-glazed collector is less expensive, safe, and usable especially in warm and temperate climates. A single-glazed collector should be given consideration for hot water heating in locations where build-up pressures and excess temperatures are a concern.

HOT WATER NEEDS

An average family of four persons uses, in the United States, about 80 gallons of hot water each day. At a customary supply temperature of about 140°F, the amount of heat required if the cold inlet is at 60°F is about 50,000 BTU per day.

There is a wide variation in the solar availability from region to region and from season to season in a particular location. There are also the short-term radiation fluctuations due to cloudiness and the day-night cycle.

Seasonal variations in solar availability result in a 200 to 400 percent difference in the solar heat supply to a hot water system. For example, in the winter an average recovery of 40 percent of 1200 BTU of solar energy per square foot of sloping surface would require approximately 100 square feet of collector for the 50,000 BTU average daily requirement. Such a design would provide essentially all of the hot water needs on an average winter day, but would fall short on days of less than average sunshine. By contrast, a 50-percent recovery of an average summer radiant supply of 2000 BTU per square foot would involve the need for only 50 square feet of collector for satisfying the average hot water needs.

It is evident that if a 50-square-foot collector were installed, it could supply the major part, perhaps nearly all, of the summer hot water needs, but it could supply less than half the winter requirements. If, on the other hand, a 100-square-foot collector were used in order that winter requirements could be more nearly met, the system would be oversized for summer operation and excess solar heat would have to be wasted. In such circumstances, if an aqueous collection medium were used, boiling of the system would occur and collector or storage venting of steam would have to be provided.

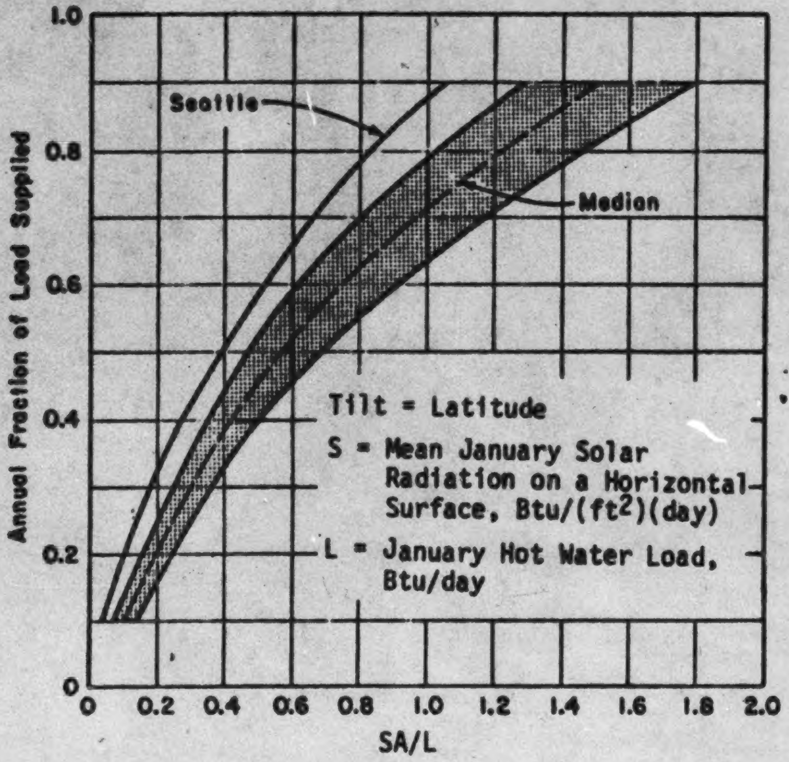
A more important disadvantage of the oversized collector (for summer operation) is the economic penalty associated with investment in a collector which is not fully utilized. Although the cost of the 100-square-foot collector would be approximately double that of the 50-square-foot unit, its annual useful heat delivery would be considerably less than double. It would, naturally, deliver about twice as much heat in the winter season, when nearly all of it could be used, but in the other seasons, particularly in summer, heat overflow would occur. The net effect of these factors is a lower economic return, per unit of investment, by the larger system. Stated another way, more BTU per dollar of investment (hence cheaper solar heat) can be delivered by the smaller system.

Overall, practical design of solar water heaters should be based on desired hot water output in the sunniest months rather than at some other time of year. If based on average daily radiation in the sunniest months, the unit will be slightly oversized and a small amount of heat will be wasted on days of maximum solar input. Then, quite evidently, on cloudy days during the season, some auxiliary heat must be provided. In the month of lowest average solar energy delivery, typically one-half to one-third as much solar heated water can be supplied, or actually the same quantity of water but with a temperature increase above inlet only one-half to one-third as high. Thus, fuel requirements for increasing the temperature of solar heated water to the desired (thermostatted) level could involve one-half to two-thirds of the total energy required for hot water heating in a mid-winter month.

SIZING

It should be remembered that the service hot water load will be nearly constant throughout the year while the solar energy collected will vary from season to season. A system sized for January, with collectors tilted at the latitude angle, will deliver high temperature water and may even cause boiling in the summer. On the other hand, a system sized to meet the load in July will not provide all of the load in the winter months. Orientation of the collector can partially overcome month-to-month fluctuations in radiation and temperature.

The following sizing curves are approximate and should not be expected to yield results closer than 10 percent of actual value.



Fraction of Annual Load Supplied by Solar as a Function of January Conditions for Hot Water Heaters

Sizing Examples:

A-1. Determine the approximate size of collector needed to provide hot water for a family of four in a residential building in Liberal, Kansas.

Solution: The average daily service hot water load in January is:

$$L = 80 \text{ gallons/day} \times 8.34 \text{ pounds/gallon} \times 1 \text{ BTU/(lb)}(^\circ\text{F}) \times (140^\circ\text{F} - 55^\circ\text{F}) = 56{,}712 \text{ BTU/day}$$

The desired service water temperature is 140°F and the temperature of the cold water from the main is 55°F. The total average solar radiation, S, available in January, taken from page A-36, is 940 BTU per square foot per day. For a water system to provide 60 percent of the annual load, from page A-34, SA/L is about 0.8. Therefore:

$$A = 0.8 \times L/S = (0.8 \times 60048)/680 = 48.3 \text{ square feet}$$

If 3-by-8-foot collector modules are available, 2.0 units would be required.

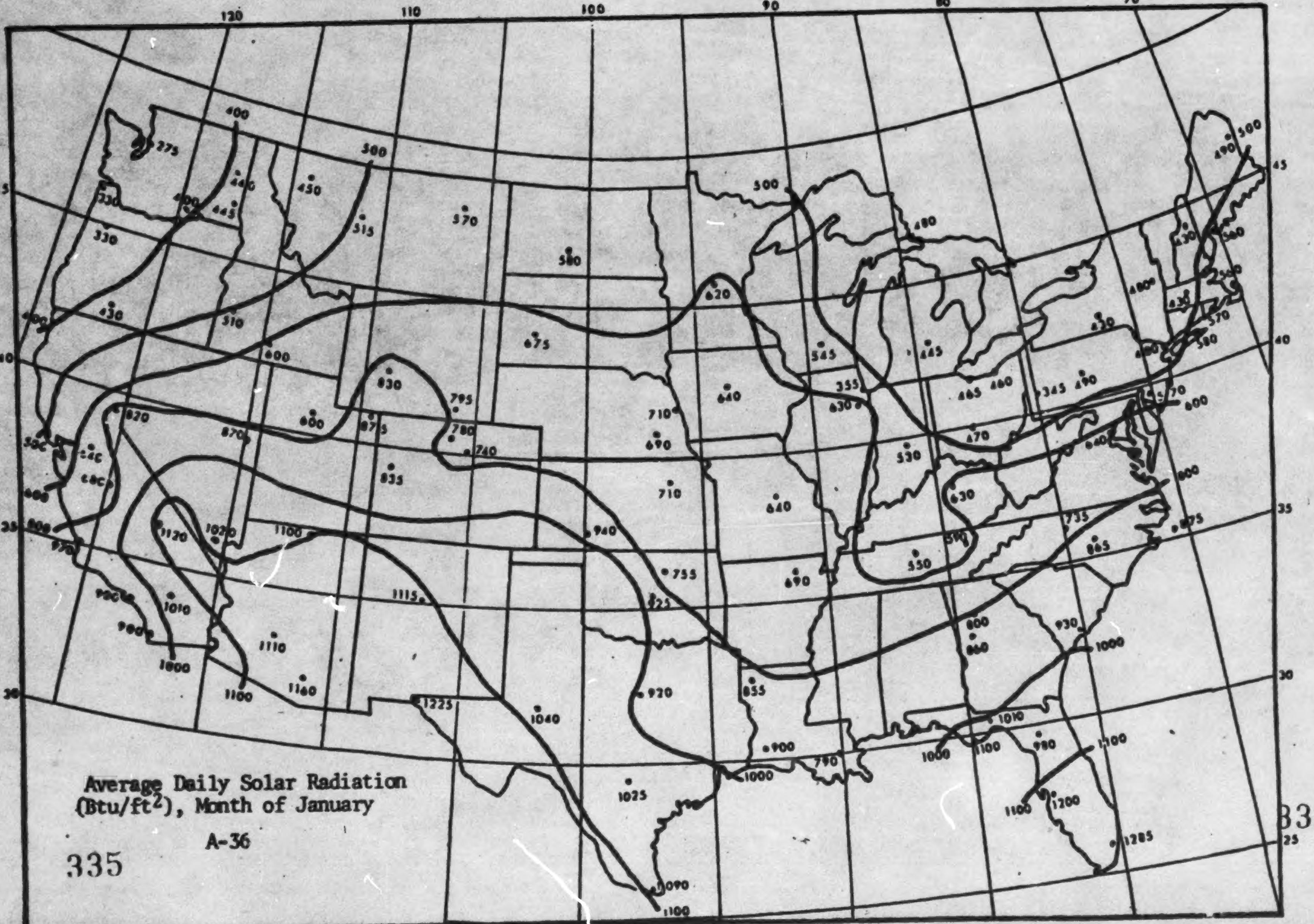
Example:

A-2. Determine the size of collector needed to provide hot water for a family of four in Albuquerque, New Mexico.

Solution: The monthly load will be approximately the same as in Example A-1:

$$L = 56{,}712 \text{ BTU/day}$$

From page A-36, $S = 1115 \text{ BTU/(ft}^2\text{)(day)}$. For a system to provide 60 percent of the annual load, page A-34 shows that SA/L is approximately 0.8.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1010
900
1000
1115
1110
1160
1100
1225
1040
920
835
800
860
930
1000
1010
1100
980
1100
1000
900
790
1000
1025
990
1200
1100
1285
1090
1100

Average Daily Solar Radiation (Btu/ft^2), Month of January

A-36

The collector area required is:

$$A = (0.8 \times 60048)/1115 = 40.7$$

Using 3 by 6 foot collector modules, 2.3 units would be required for this system--either two or three modules should be used. If two modules are used, the system would be expected to provide less than 60 percent of the annual load.

COURSE VIII: SOLAR HEATING AND COOLING SYSTEMS

MODULE A: SYSTEM DESIGNS

UNIT II: TYPES OF SYSTEMS

HANDOUT 2: SWIMMING POOL HEATING

Solar collectors can be used to heat swimming pools that are both indoors and out-of-doors. Collectors used to heat outdoor pools are usually less elaborate than space heating collectors simply because they are used in the spring and summer months. Thus, single glazed or even unglazed absorber panels can be used. Many unglazed panels are made of plastic or rubber as well as metal. However, in the case of metal, swimming pool water is never circulated through all-aluminum panels because of excessive corrosion.

Under natural conditions, pool water will gain some heat during the day and then lose some heat at night. Typically, pool water may exceed the average ambient temperature by up to 10 degrees under these conditions.

Outdoor swimming pools lose heat in several ways, namely by:

1. conduction through the pool material to the ground.
2. convection at the pool surface.
3. evaporation at the pool surface.
4. radiation at the pool surface.

Conduction losses are usually small relative to the other modes of heat loss. Thus, to make full use of any solar assist (natural or with panels), outdoor pools should be provided with pool covers so that convective, evaporative, and radiation losses are minimized.

One type of pool cover of particular interest to the solar technician is the transparent cover. This product allows considerable solar energy to pass through during the day to help heat the pool water as well as minimize pool heat losses at night.

Considering typical pool heat losses, the usual rule-of-thumb sizing procedure suggests that, for adequate performance, the collector area should equal half the pool area for south facing collectors. For other directions, additional area is required.

Proper tilt depends on the season of the year for which pool heating is desired. In northern climates, pool heating is generally required in the summer, thus the preferred tilt is latitude minus 10 degrees. In southern areas, winter pool heating might be the objective. In this case, the preferred tilt is latitude plus 10 degrees.

Most manufacturers of collectors intended for pool applications offer design assistance and make recommendations on control of the system.

COURSE VII: SOLAR HEATING AND COOLING SYSTEMS

MODULE A: SYSTEM DESIGNS

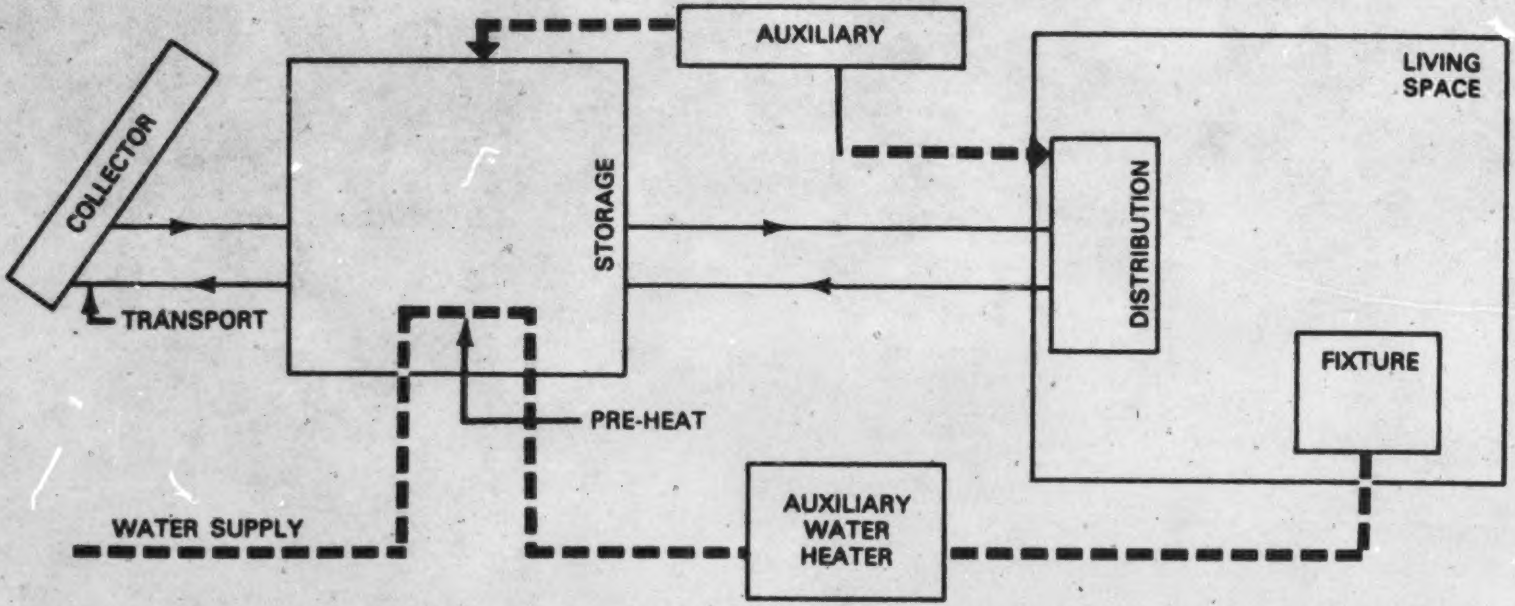
UNIT II: TYPES OF SYSTEMS

HANDOUT 3: SPACE HEATING

Solar heat from the collectors and the heating demand for a building are not normally in balance. Thus, mechanical equipment is required for proper comfort control. The central component of the solar system is the heat storage unit. The heat storage unit receives heat from the collectors when the solar heat exceeds the heating load and delivers heat to the rooms when the heating load exceeds the solar heat available from the collectors. When solar heat has been depleted from storage, the auxiliary boiler or furnace supplies the heat to meet the heating load. The system should be easy to operate, require little maintenance, and provide the comfort level demanded by the occupants in the building.

The most commonly used solar system today is a combined solar heating and domestic hot water system. Solar radiation is absorbed by a collector and removed by a heat transport medium to storage. Heat is removed from storage and distributed to the living spaces by a heat transfer medium (not necessarily the same medium flowing through the collector).

SOLAR HEATING AND DOMESTIC HOT WATER SYSTEMS: PROCESS DIAGRAM


AUXILIARY
LIVING SPACE
COLLECTOR
STORAGE
DISTRIBUTION
TRANSPORT
PRE-HEAT
FIXTURE
WATER SUPPLY
AUXILIARY WATER HEATER

Pumps, blowers, or other heat transfer medium-moving devices provide the circulation throughout the system. An auxiliary energy system is available both to supplement the output supplied by the solar system and to provide for the total energy demand should the solar system become inoperable. Manual or automatic controls maintain and monitor system operation. Domestic hot water is preheated by passing the water supply through a heat storage before its passage through a water heater.

By the positioning of three-way dampers (or valves) and the controlling of blowers (or pumps) on or off, three "modes" of operation are possible:

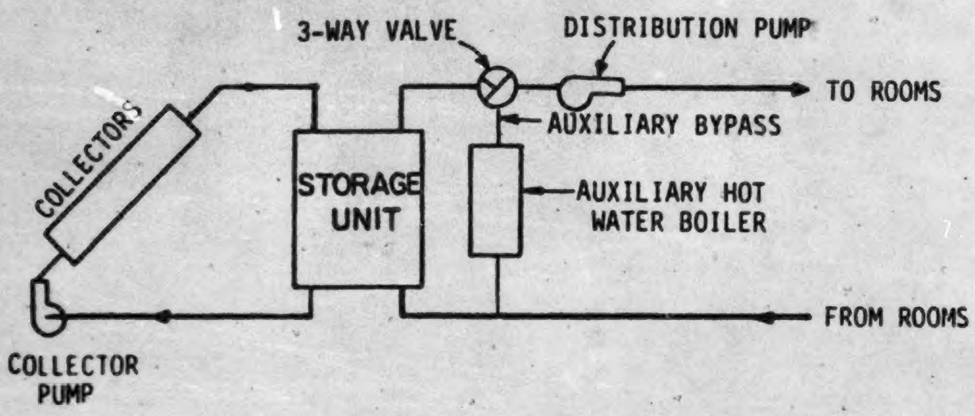
1. Heating the building directly from the collectors
2. Heating the storage unit from the collectors
3. Heating the building from the storage unit

In a water system the collection and distribution circuits may each be connected to the water storage tank and the three-way valves may be eliminated. The three modes are obtained by on and off control of the two pumps.

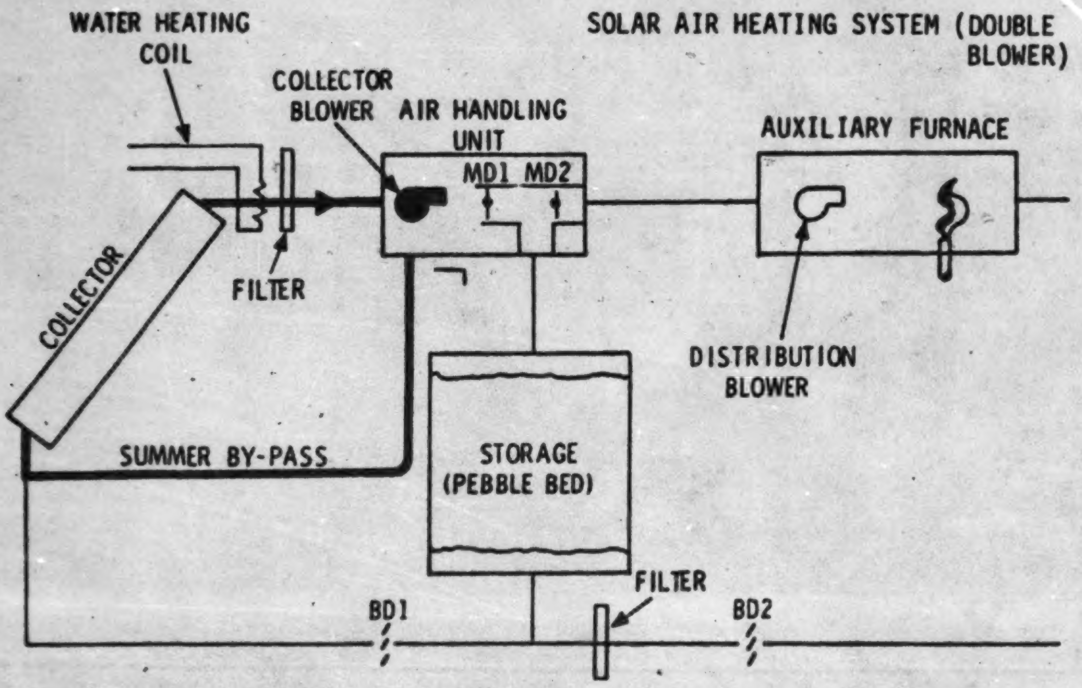
Since there are periods when neither the collectors nor the storage unit can meet the demand for heat, an auxiliary heater (fuel or electric) having the capacity to carry the maximum heating load is required. Solar and auxiliary heat may be supplied to the building by the same heat distribution system. The air heating solar system may use a conventional warm-air furnace directly in the hot air supply duct. Fuel is supplied to the auxiliary unit only when solar heat is insufficient to maintain the desired room temperature.

In the liquid system a hot water boiler (fuel or electric) is used, preferably locating the boiler in a by-pass circuit as shown on the following page. The boiler by-pass is used to prevent heating the storage with auxiliary energy. Heat from the auxiliary boiler should not be supplied to the storage tank because it is wasteful use of energy.

Liquid System for Solar Space Heating with Auxiliary Boiler


3-WAY VALVE
DISTRIBUTION PUMP
TO ROOMS
AUXILIARY BYPASS
COLLECTORS
STORAGE UNIT
AUXILIARY HOT WATER BOILER
FROM ROOMS
COLLECTOR PUMP

So that the domestic hot water supply can be solar heated in the summer when no space heating is needed, the heat storage unit and heated space can be by-passed as shown below.


WATER HEATING COIL
SOLAR AIR HEATING SYSTEM (DOUBLE BLOWER)
COLLECTOR BLOWER
AIR HANDLING UNIT
MD1
MD2
AUXILIARY FURNACE
COLLECTOR
FILTER
DISTRIBUTION BLOWER
SUMMER BY-PASS
STORAGE (PEBBLE BED)
FILTER
BD1
BD2

Service Hot Water Heating (Summer Operation)

A manual damper is opened in the by-pass duct so that air is circulated in a closed loop between collector, water heating coil, and the collector blower. Damper MD 1 in the closed position prevents flow of hot air to storage or the rooms.

Most commercially available warm-air furnaces for residential use contain a blower for circulation of warm air through the building via the distribution ducts. In a typical all-air solar installation, the furnace blower is used in the normal manner for distributing warm air--supplied either from the collectors or from storage. The solar system blower operates only when air is circulated through the collector.

SOLAR AIR SYSTEM, COMPONENTS, AND INSTALLATION

Important operating considerations in the air type system are blower power requirements and air leakage. A well-designed air system has approximately equal pressure loss through the collectors and pebble-bed, typically about 0.3 inch water guage in each unit. With ducting and filters, the total system pressure can near one inch of water. The total pressure in an air type solar system is about double that usually encountered in a conventional forced air distribution system, so additional blower power is needed. Typical requirement in a conventional system is one-half to three-fourths horsepower for a 1500 cfm system. The blowers also run for longer periods of time than in the conventional system because of their use both for solar heat collection and for heat distribution. A one-inch water guage pressure loss is about the maximum acceptable from the standpoint of blower power cost.

Leakage of air in ducts, collectors, and storage is of more concern in a solar heating system than in a conventional system because the pressure is higher, there is more ducting, the system operates for longer periods, and there may be more ducting through unheated space. The ducts should, therefore, be made with sealed joints and tightly fitted dampers. The ducts may be of fiberglass board or insulated sheet metal. Insulation is required to reduce heat loss through the duct walls, particularly in unheated spaces such as attics, At least one inch of fiberglass with a rating of R-4 is recommended for duct insulation.

It is especially important with a solar air system that a well scheduled installation be made. More space and access must be provided in the building for ducting than for pipes in a liquid system. Ductwork and component assembly can be accomplished at the same time that the distribution ducts and furnace are installed in a typical construction schedule. Provision for construction and installation space and for full access to the space for systems and components is required.

If fiberglass ductboard is used for the air duct, it should not be placed where it can be damaged by moving objects or occupants. Joints should be well sealed with tapes or mastics recommended by the industry. Duct bends should be provided with turning vanes to reduce losses. Ducts should be sized for air velocities between 700 and 1000 feet per minute.

Blowers, dampers, and auxiliary heaters may be provided by a single solar system supplier or they may be purchased separately. If separately purchased, blowers should be forward-curved squirrel cage type and belt-driven at 900 to 1700 rpm. Direct connected blowers with motors in the air stream may have briefer service life because of motor operation in high-temperature air. Flexible connections between blowers and ducts are recommended.

Louver-type dampers with live silicon rubber seals are recommended for positive shut off and smooth stroking. Damper drive motors should be located on the outside of ducts and direct connected to the damper shaft or through linkages. Damper pairs may be operated by the same drive motor such that one is closed when the other is open. Damper motors are available that operate on low voltage (24 volt) and have spring returns.

Back draft dampers, used in ducts to prevent reverse flow, may be of the flexible flat type or shutter type. They must be mounted to provide a positive seal against reverse air flow.

To prevent fouling and increased pressure loss in the pebble-bed, filters should be installed in the air streams entering both ends of the storage unit. The filters should be changed or cleaned every few weeks during the first several months of operation to remove the initial dust in the system and building.

Provision for supply of domestic hot water can be easily made in the air system by the use of an air-to-water heat exchanger in the hot air duct between the collector and blower. The heat exchanger coil is a finned type, with one or two rows of tubes. A small pump circulates water from the bottom of an insulated tank (usually about 80-gallon capacity), through the coil, and back to the top of the tank. The cold water enters the solar-heated tank and warm water flows to a conventional automatic water heater whenever a hot water faucet is opened in the building. A duct by-pass allows operation of the service hot water coil in the summer without heating the pebble-bed. A thermostatic mixing valve can be installed in the line connected to the service hot water tank from the cold water main to prevent delivery of scalding hot water.

The complete solar heating installation will require heating and sheet metal workers to install collectors, ducts, dampers, plumbers to connect the domestic water heating system, and carpenters or masonry workers to construct the pebble-bed container. Consequently, the general contractor and the solar system contractor should coordinate their activities so that each task is accomplished at the most appropriate and convenient stage during construction. Quality installation is an important requirement to obtain a high performance air heating solar system.

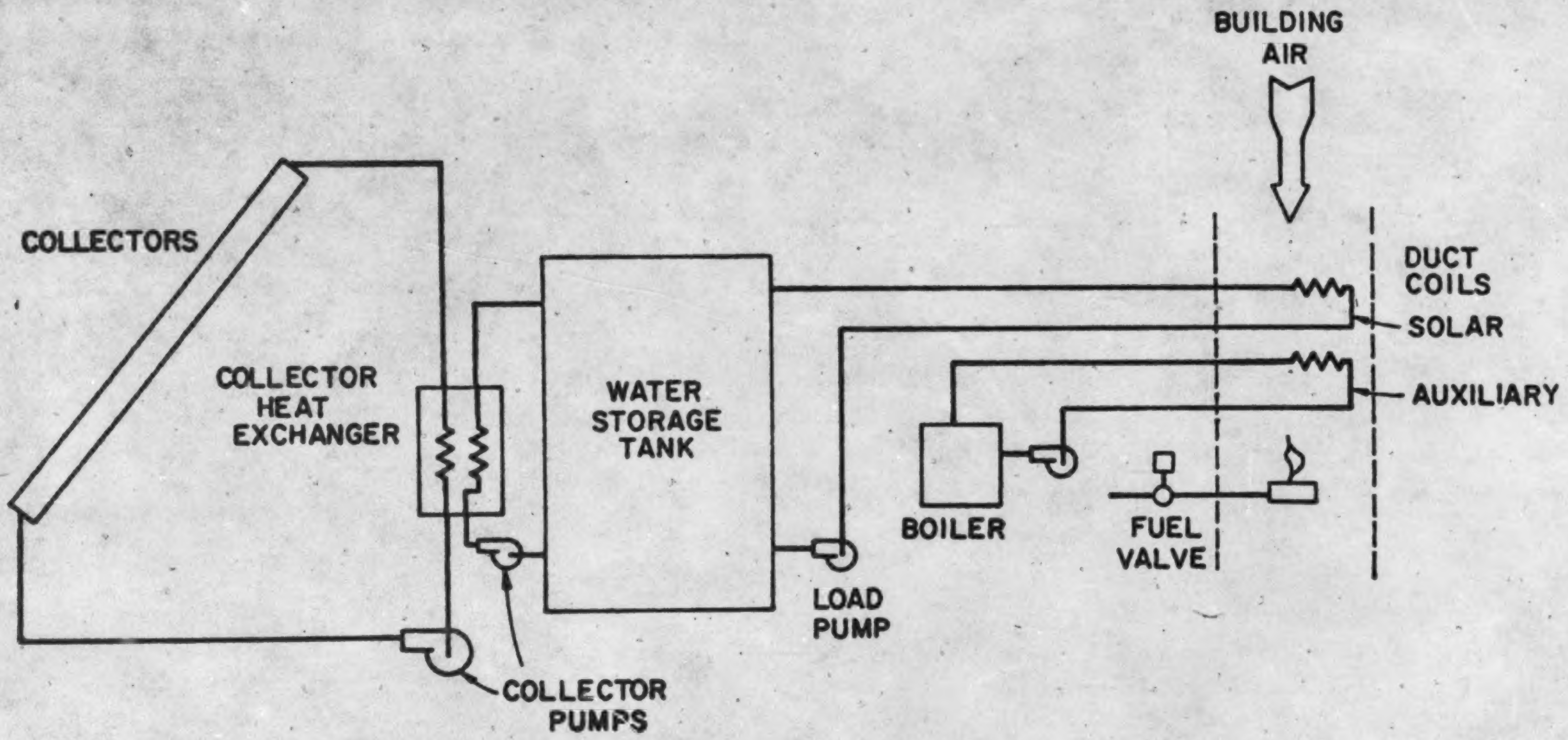
LIQUID HEATING SOLAR SYSTEM

A schematic diagram of a complete liquid-heating solar system for solar space heating using water as the heat transport and storage fluid is presented on the following page. The system is comprised of solar collectors, storage tank, auxiliary boiler, and pumps, valves, and heat exchangers.

The collector heat exchanger is used for systems in freezing climates to separate the antifreeze in the collector loop from the storage tank water. The heat exchanger may be a counterflow tube-in-shell type.

A central heat distribution system with a single heat exchanger coil or multiple fan coil units in different zones in the building may be used to heat the rooms. Radiant or baseboard convection heating is an alternative method for heat delivery but for satisfactory performance, higher temperatures are required than for forced air heat exchangers. The higher temperature is a disadvantage to system operation with flat-plate collectors. The auxiliary heater may be either a boiler or an air duct furnace.

A-49


BUILDING AIR
COLLECTORS
DUCT COILS
SOLAR
COLLECTOR HEAT EXCHANGER
WATER STORAGE TANK
AUXILIARY
BOILER
FUEL VALVE
LOAD PUMP
COLLECTOR PUMPS

Water Type Solar Space Heating System

NOTE: EITHER BOILER OR DUCT HEATER IS USED

Solar Water System Components and Installation

Piping may consist of either copper or high temperature (CPVC) plastic pipe and all pipes should be insulated with appropriate material such as neoprene foam at least one-half inch in thickness. Care should be taken to allow thermal expansion of the pipes, and long pipe lengths should provide more freedom for expansion than short lengths. Pipes should be sized so that water velocity does not exceed five feet per second. In the table below, recommended pipe diameters are indicated for flow rates in gallons per minute.

Select Pipe Size	Gallons per Minute	Velocity FPS	Pressure Drop per 100 feet PSI
3/8	2	3.36	6.58
1/2	4	4.22	7.42
3/4	8	4.81	6.60
1	15	5.57	6.36
1-1/4	25	5.37	4.22

Recommended Pipe Diameters for Various Flow Rates

Circulating pumps should be centrifugal type, coupled directly to motors with rotating speeds between 700 and 1700 rpm. Centrifugal pumps are recommended because the pumping pressure is limited and if valves fail to open, or the pipeline becomes clogged, there is no danger of developing excessive pressures which could burst pipes. With known flow rate and system head, pumps may be selected from stock items in catalogs, or made to specifications by pump manufacturers. Impellers of stock item pumps may be trimmed to meet the specifications. Centrifugal pumps should be located so that priming is not necessary, which could be a particular problem in a vented system or where a storage tank is underground. The pumps should be provided with at least five feet of head on the suction side.

SOLAR HEAT PUMP SYSTEMS

Heat pumps which operate on a conventional vapor compression cycle are currently one of the most efficient heating systems. The system is usually reverse cycle, thus it can be applied to both heating and cooling. Basically, in the heating mode, heat is extracted from the outside air (or some other heat sink, such as an insulated tank of water) and pumped into the space to be heated. The cooling mode is essentially the opposite. Heat is extracted from the inside air via the vapor compression cycle and pumped to the outside. Currently available units use air-to-air, air-to-water, and water-to-water cycles. They are typically powered by an electric motor which derives the compressor and pump.

In a heat pump, the heat source should be kept as close to the design temperature point as possible in order to insure proper efficiency. This presents somewhat of a problem during the winter, since ambient temperatures drop relative to inside heating temperature requirements. Then solar/thermal energy can be applied in a solar/heat pump system.

Typically, solar/heat pump systems fall under three classifications:

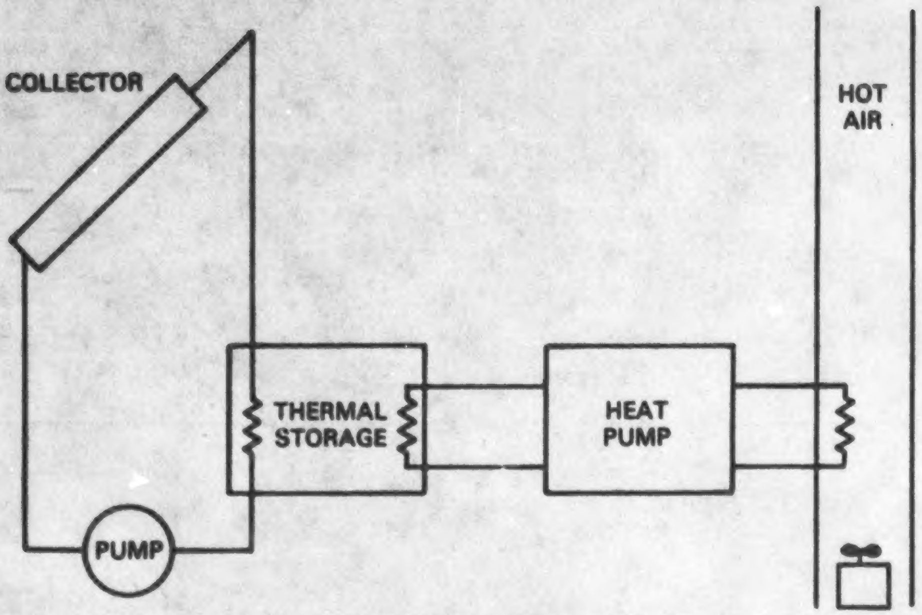
1. Solar Boosted
2. Solar Assisted
3. Solar Driven

The first two systems are illustrated schematically on the following page.

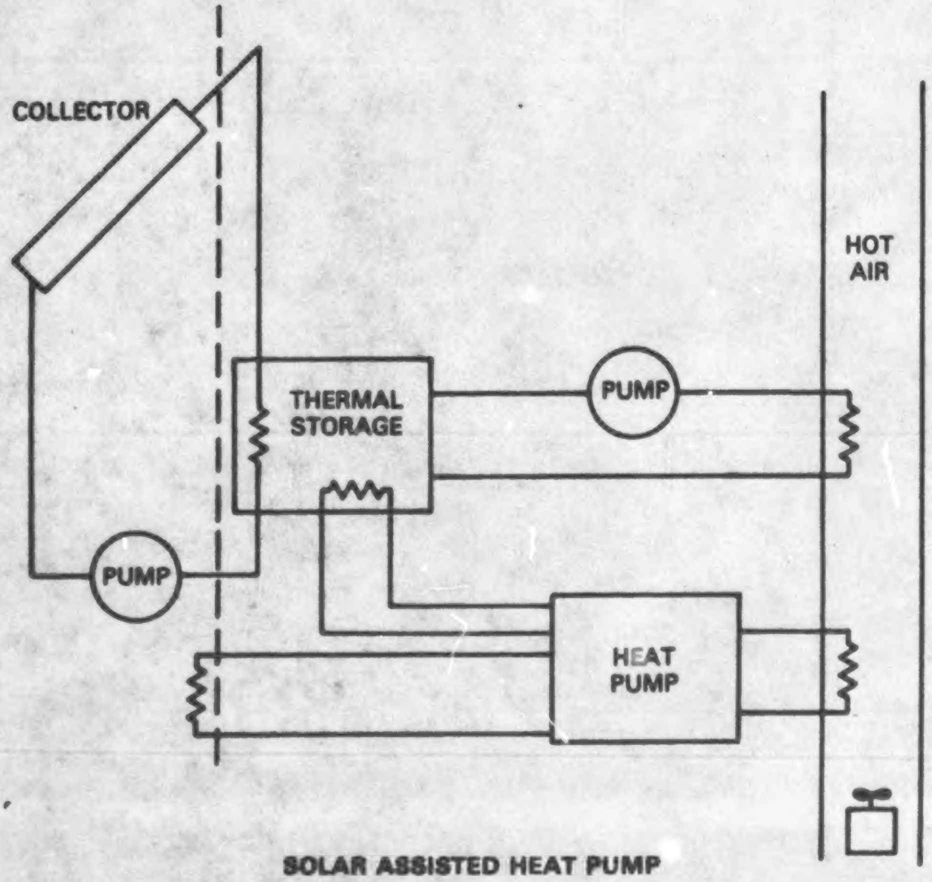
In a conventional heat pump configuration, a liquid heat exchanger which can use solar heated water is substituted for the air heat exchanger. This raises the heat source temperature relative to the ambient temperature, thus providing a solar "boost" to the conventional system hence the name "solar boosted heat pump." The solar heated fluid supplied to the heat pump unit also can come from the thermal storage system during periods of no sunlight.

The solar assisted heat pump might more aptly be called a heat pump assisted solar system. In this configuration, the heat pump is used to provide supplementary heating when the solar system and/or storage system cannot meet the heating requirements alone. In this case, the heat pump can use the relatively low (although still usually higher than ambient) temperatures of the storage unit as a heat source or it can extract heat directly from the outside environment.

The concept of a solar-assisted heat pump is to supply


COLLECTOR
HOT AIR
THERMAL STORAGE
HEAT PUMP
PUMP

SOLAR BOOSTED HEAT PUMP


COLLECTOR
HOT AIR
THERMAL STORAGE
PUMP
PUMP
HEAT PUMP

SOLAR ASSISTED HEAT PUMP

a higher temperature heat source than outdoor ambient air to the heat pump from solar collectors or storage. Typically, solar heated air or water could be 40° to 110°F above the ambient air or water temperature. Because the fluid temperature delivered from the collectors is low, greater efficiency is expected from the solar system as compared to a solar system using direct heating methods, which typically requires 150°F water temperatures above ambient. A solar heat pump system is appropriate in extremely cold, windy, or cloudy areas where flat-plate collectors could be used effectively to collect solar energy at temperatures sufficient for a heat pump.

Heat is usually stored for the low temperature side of the heat pump because it results in better system efficiency and smaller size unit than if storage is provided in the "hot side". Solar air heating collectors with a pebble-bed storage unit or liquid heating collectors with water or phase change storage may be used along with any of the three types of heat pumps available commercially.

There is not yet a clear indication of what heat pump arrangement is going to prove best. With an air system, it appears that the heat pump can be most advantageously used if operated simply as the auxiliary furnace to raise the temperature of the circulating air from the pebble-bed to the rooms. In the liquid system, whether the heat pump should be used in a similar fashion, or whether the source should be the solar storage tank, is not yet clear. At this time, an engineer and the heat pump manufacturer should be consulted to assist in the design of a solar heat pump combination.

COURSE VIII: SOLAR HEATING AND COOLING SYSTEMS

MODULE A: SYSTEM DESIGNS

UNIT II: TYPES OF SYSTEMS

HANDOUT 4: SOLAR COOLING

Solar cooling may be achieved by the addition of certain components, some of which are already on the market (others are in the development stage), to a baseline solar heating system similar to those presented. Solar cooling thus implies, in most cases, a solar heating and cooling system. However, solar cooling requires significantly higher working fluid temperatures than those typically used in space heating applications. These higher temperatures can usually be attained with the use of advanced collector systems such as focusing or tubular glass collectors.

Review "Module A: Collectors" which may be found under "Course VII: Collectors and Energy Storage".

Review "Unit III: Cooling Systems" which may be found under "Module 9".

COURSE VIII: SOLAR HEATING AND COOLING SYSTEMS

MODULE B: RETROFITTING

UNIT I: TYPICAL PROBLEMS

HANDOUT 1: INTRODUCTION

Retrofit for the present purpose means the adaptation of solar systems to existing buildings. There are many owners of residential buildings who are experiencing rising costs for heating, and consequently, a strong interest is developing in retrofitting solar systems to existing structures. Solar system designs for existing buildings are fundamentally the same as for new buildings. However, there are many factors concerning installation that need to be considered in retrofitting--factors that are not involved in new construction. These factors relate to the structural and mechanical features of existing buildings and to the cost of installation. Each installation is a special case and generalizations of problems are difficult.

INSULATION

Although insulating a building is not strictly a feature of solar energy systems, it is known that there is a significant impact on solar systems with energy conservation designs in buildings. Many existing residential buildings have little or no insulation in the walls and ceilings and the heat loss rate is therefore large. If a solar system is contemplated, an initial step is to insulate the building.

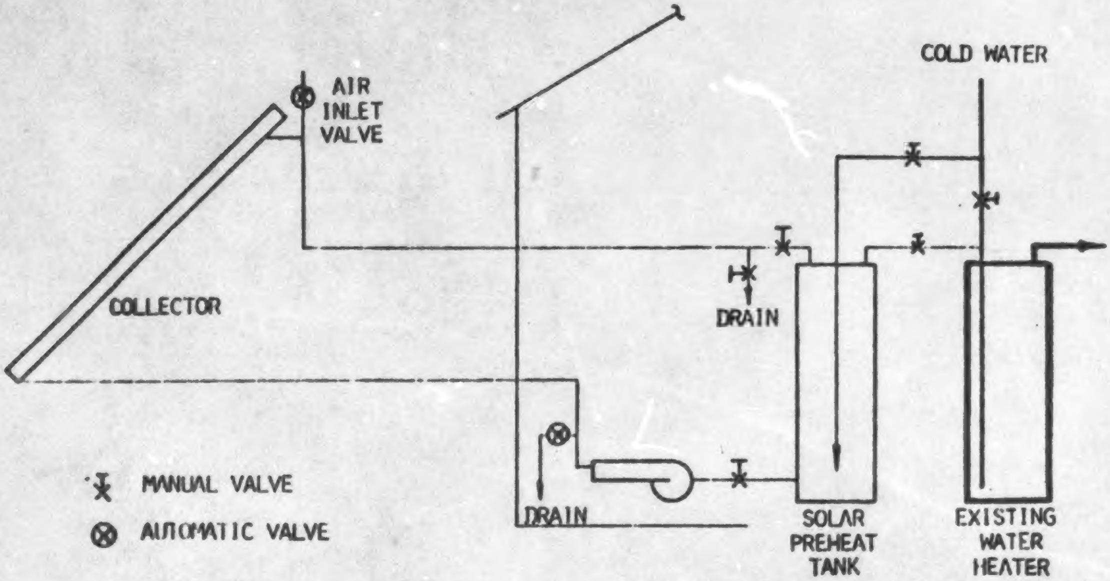
If the cost for adequately insulating the building is high, an economic analysis to determine benefits and cost is recommended.

TREES AND LANDSCAPE

The availability of sunshine for the particular building is of major importance. There are many existing residential buildings that have been landscaped liberally with trees for the specific purpose of shading the building and at least some of the trees will have to be eliminated. Although solar radiation will filter through leafless branches of deciduous trees during the winter, the reduction in useful sunshine could greatly affect the system size and performance. An alternative to eliminating is to reduce the height, but this will invite an annual or periodic maintenance cost that is chargeable to the solar system.

There are many locations where buildings on hillsides are shaded by neighboring structures. Solar systems for buildings that are in shadow a portion of the day will necessitate an unusual orientation of the collectors with consequent increase in collector area and system cost.

DOMESTIC HOT WATER SYSTEM


AIR
INLET
VALVE
COLD WATER
COLLECTOR
DRAIN
DRAIN
MANUAL VALVE
AUTOMATIC VALVE
SOLAR
PREHEAT
TANK
EXISTING
WATER
HEATER

Retrofit Solar Domestic Hot Water Heater, Freezing Climates

Domestic hot water retrofit systems are being considered in many regions of the United States. There is no basic difference in system configuration for new and retrofit construction. However, depending on the site, it may be necessary to situate the collectors away from the building.

In freezing climates, it is advisable to locate the preheat tank inside the building. Provision for drainage is necessary for direct heating systems.

SPACE HEATING

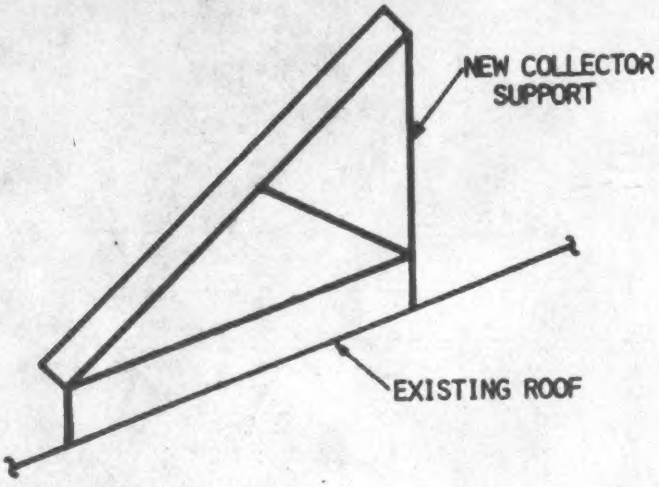
There are several potential difficulties involved in providing retrofit solar space heating systems. These problems concern:

1. Collector location
2. Equipment location
3. Adaptation to the existing heating system.

Collector Location

Collectors can be advantageously mounted on the roof of new buildings if the weight of the collectors can be supported. Otherwise, collectors will have to be supported on a separate structure on the ground. In new construction, the roof pitch is set at the desired collector tilt angle to maximize the collection of solar energy for a particular orientation, but in retrofit situations, the roof pitch normally is 5 on 12, or 22.6° from horizontal. This angle is too flat for solar collectors in most locations so a separate frame is needed to mount the collectors at a more suitable angle. One possible arrangement is illustrated on the following page. The "add on" appearance of the collectors and supports may be aesthetically unsatisfactory to some home owners. When aesthetics govern, either the entire roof must be reconstructed to blend them architecturally with the building, or the collectors must be placed at ground level. Removal and reconstruction are

Collector Frame Supports On Roof



expensive and although there may be beneficial effects in the renovation other than to accommodate collectors, the costs will be chargeable to the solar system.

When collectors cannot be placed on the building roof, they must be placed at ground level and preferably on the south side adjacent to the building. Placing collectors at ground level offers some advantages and some disadvantages. One advantage is lower pumping head. Another is that piping and ducting to the collector banks are easier to install than in the attic of an existing building with a low-pitched roof. Maintenance of collectors at ground level is easier. The disadvantages are that the collector array may offer hazards to the occupants, and pipes and ducts are in unheated areas or exposed to the outside air. Insulation around pipes and ducts must be thick to reduce heat losses.

The location of equipment needed for solar heating and cooling systems may offer difficulties for some retrofit installations. The bulkiest equipment that has to be installed is the storage tank for a hydronic system and a rock bed for an air system. The most easily accessible area in the building is at ground floor level. However, ground floor space is expensive compared to comparable space in the basement or garage.

The fabrication of storage tanks and rock boxes in basements, or placing of rocks in storage, are restrictive activities in retrofit installations. The walls of rock bed storage containers can be fabricated relatively easily, but fabricating tanks for water storage could be more difficult. Tanks may be fabricated inside by either welding or bolting sections together, and if bolted tanks are used, neoprene or butyl rubber lining is recommended to prevent leaks from the bolted seams.

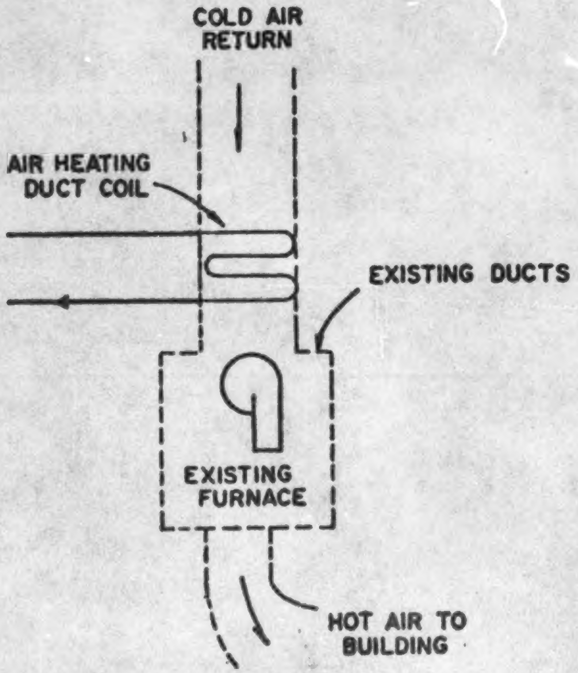
Locating the storage tank or rock bed in the garage offers the simplest installation for retrofit situations. Adaptation to the existing heating system with the storage tank in the garage may require longer pipes and ducts than if storage were located inside the building. The biggest disadvantage with storage located in the garage is that the heat loss from storage is not recovered as useful heat in the building enclosure.

It is recommended that heat exchangers and pumps be located close to the storage tank for hydronic systems to minimize head losses and economize on space. The appurtenant equipment such as pumps and heat exchangers will not occupy much space. Maintanance will also be facilitated if all of the equipment is located in one place.

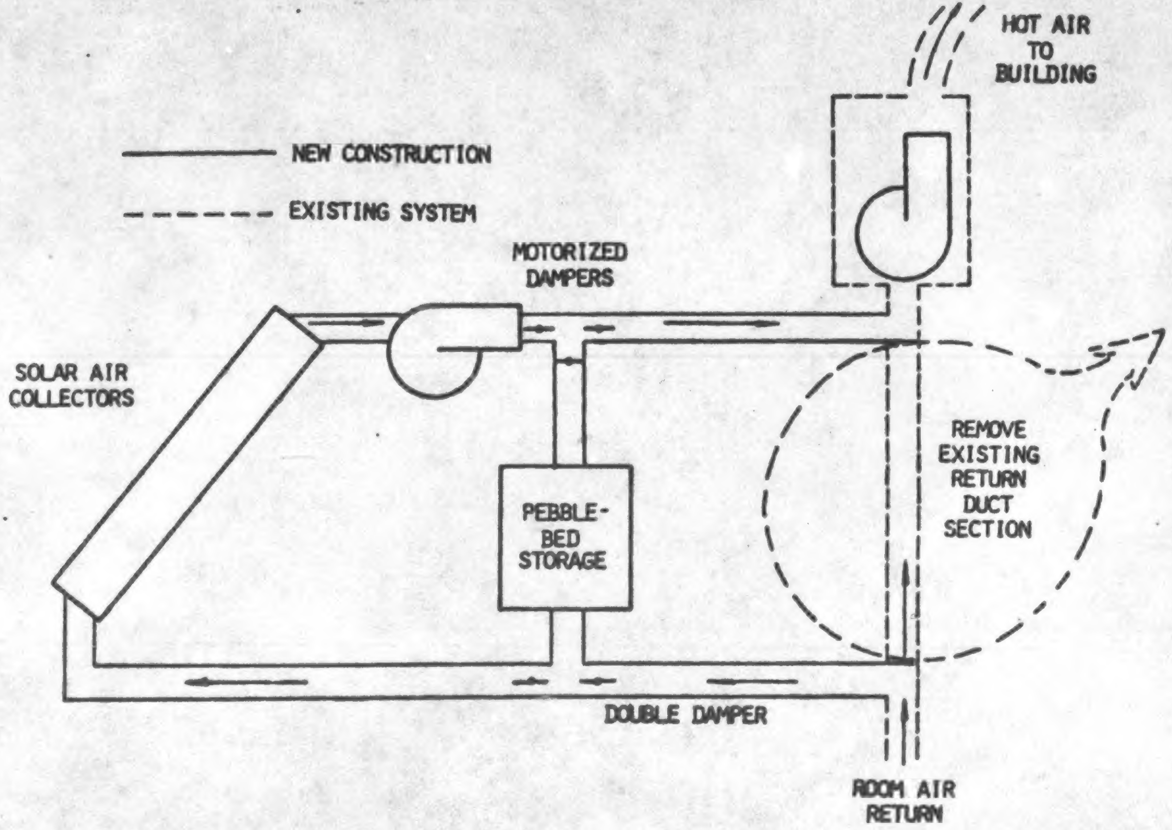
Adaptation to Existing Heating Equipment

The solar heating and cooling systems discussed in this manual are for central air distribution systems. Adaptation of solar systems to existing buildings is likewise facilitated if a central distribution system exists. While baseboard heating systems are prevalent in many non-solar hydronic systems, flat-plate collectors will not function well with such systems. Fan coil units are recommended for such retrofit installations.

A difficulty in adapting to an existing air-heating system is illustrated on the following page. Usually, the blower is an integral part of a furnace. The heating element, whether fuel-fired or electric, is coupled to the blower. The controls must be arranged so that the blower is independent of the heat unit. Whether the blower is after the heating coil (as shown in the above illustration on the following page) or before would not matter, particularly if the motor to drive the blower


COLD AIR RETURN
AIR HEATING DUCT COIL
EXISTING DUCTS
EXISTING FURNACE
HOT AIR TO BUILDING

Hydronic Solar System for Retrofit Installation


HOT AIR TO BUILDING
NEW CONSTRUCTION
EXISTING SYSTEM
MOTORIZED DAMPERS
SOLAR AIR COLLECTORS
PEBBLE-BED STORAGE
REMOVE EXISTING RETURN DUCT SECTION
DOUBLE DAMPER
ROOM AIR RETURN

Air-Heating Solar System for Retrofit Installation is outside the duct. The location of the water-to-air heating coil is dependent upon the existing duct arrangement.

An air solar system might be arranged as shown in the lower illustration on the previous page. A two-blower system is most suitable for retrofit installations. The existing blower will have to be decoupled from the heating element control as discussed before and the dampers shown in the illustration will control the different modes of operation.

COURSE VIII: SOLAR HEATING AND COOLING SYSTEMS

MODULE C: SERVICING

UNIT I: MAINTENANCE

HANDOUT 1: MAINTENANCE PROCEDURES

Solar systems are expensive. Obviously, if the owner is to receive the expected return on his investment, the system must operate at peak design efficiency. This objective can be achieved through proper system maintenance.

MAINTENANCE OF LIQUID SYSTEMS

1. Check condition and/or operation of collectors, piping and supports, heat exchangers, storage tanks, preheat tanks, expansion tanks, pumps, relief valves, automatic air vents, tempering valve, ductwork, excess heat rejection unit, etc.
2. Check condition of thermal insulation on piping, storage tanks, and ductwork.
3. Check fluid levels and flow in each hydronic circuit.
4. Check antifreeze concentration in collector circuit. Add antifreeze as required.
5. Lubricate pump and blower motors.

6. Check blower wheels for alignment and clean as required. If belt driven, adjust belt tension.

7. Change or clean all air filters.

8. Check and adjust air flow through furnace or air handling unit.

9. Check control system for proper placement of sensing elements, condition of control devices and associated wiring, and proper operation of the various control modes.

10. If system also includes solar powered air conditioning, perform routine maintenance as suggested by the equipment manufacturer.

MAINTENANCE OF AIR SYSTEMS

1. Check condition and/or operation of collectors, ductwork, dampers, and heat storage unit.

2. If system also includes a domestic hot water system, check condition and/or operation of preheat tank, pump, relief valve, automatic air vents, and tempering valve.

3. Check condition of thermal insulation on ductwork, heat storage unit, and domestic hot water preheat tank and piping.

4. Lubricate blower and pump motors.

5. Check blower wheels for alignment and clean as required. If belt driven, adjust belt tension.
6. Change or clean all air filters.
7. Check and adjust all flows through collectors, heat storage unit, and furnace.
8. Check control system for proper placement of sensing elements, condition of control devices and associated wiring, damper operators, and proper operation of the various control modes.

COURSE VIII: SOLAR HEATING AND COOLING SYSTEMS

MOCULE C: SERVICING

UNIT II: TROUBLESHOOTING

HANDOUT 1: TROUBLESHOOTING PROCEDURES

Exact troubleshooting procedures are, of course, determined by the particular system involved. However, regardless of the type system, the primary function of all systems is to transport heat by means of liquids and/or air. Thus, troubleshooting becomes a matter of understanding the operational modes of the particular system, measuring all applicable variables, and making visual observations of equipment condition.

Following are some problems which may contribute to loss of system efficiency or complete operational failure.

1. Solar Collectors
    - A. Dirty, cracked, or broken glazings
    - B. Unexpected shading by newly planted trees or new buildings.
2. Controls
    - A. Defective or improperly mounted temperature sensors.
    - B. Defective control wiring.
    - C. Defective valve or damper operators.
    - D. Primary control malfunction (refer to manufacturer's literature for check-out procedure),

3. Leaks in Ductwork

A. In an air type system, air is usually drawn through the collector. If the ductwork is leaking, cold air will be drawn into the system. An unusually high temperature drop from collector outlet to blower inlet is a good indication of such leakage.

B. Leakage of warm or hot air out of ductwork will also affect system performance. This situation can exist between blower outlet and collector inlet and in the building air distribution system. Measuring air flows and temperatures will aid in detection of this problem.

4. Restricted Air Flow

This problem can exist in either the collector loop or air distribution system. Some possible causes are:

A. Dirty filters

B. Blockage by fallen internal duct liners

C. Dirty blower wheels

D. Slipping drive belts

E. Dirty coils (heating, cooling, or domestic hot water)

F. Improper electrical speed taps on direct drive blowers

   G. Slipping damper linkage
   H. Crushed ductwork
   I. Furniture, drapes, or carpets covering air inlets or outlets
   J. Improperly positioned manual dampers
   K. Closed fire or smoke dampers

5. Liquid Leaks
   A. Collector (due to corrosion or freezing)
   B. Piping
   C. Pump seals

6. Damaged Thermal Insulation
   A. Piping
   B. Storage units
   C. Ductwork

7. Heat Exchangers
   A. Excessive scaling due to poor water conditions
   B. Restricted flow due to presence of foreign materials

8. Tools and Instruments
   A. Hand tools--common to the HVAC industry.
   B. Instruments
      a. thermometers
      b. pressure gages
      c. volt-ampere meter
      d. ohm meter
      e. velometer--measure air flow
      f. flow meters--measure liquid flow
      g. hydrometer--check antifreeze concentration
      h. pyranometer--measure solar radiation

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LOOK TO THE SUN. 1977. 12-½ minutes, 16 mm, color, $69.50/ purchase; free loan.

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